THE LLANDOVERY TRANSGRESSION OF THE WELSH BORDERLAND

by A. M. ZIEGLER, L. R. M. COCKS, and W. S. McKERROW

ABSTRACT. The study of the evolution of several brachiopod genera has enabled the early Silurian shelf sequences of the Welsh Borderland to be correlated with the type area of Llandovery, and, to some extent, with the graptolite zonal sequence. The transgression across the Borderland started at the beginning of Llandovery time, when areas in Montgomeryshire became inundated after a short break in deposition at the end of the Ashgill. The sea reached Shropshire, and possibly as far east as the Malverns and May Hill, by Middle Llandovery times. By late Upper Llandovery times, much of the English Midlands were covered.

Fossil communities indicate the relative depths in which the Llandovery sediments were deposited. With the advance of the sea, most sequences show a progressive increase of depth with time, although minor reversals are known. The many gaps in the local sequences are probably due to submarine erosion or non-deposition, rather than to uplift and sub-aerial erosion, because they are characteristically followed by progressively deeper-water communities. The community distribution indicates that a continuous gradient was maintained from the coast to the shelf margin, once the topographic relief of the original surface had been filled in.

DURING the Lower Silurian there was a spread of the shelf sea from Central Wales over the Welsh Borderland (text-fig. 1). Brachiopods are the dominant element in the shelf faunas of this region. Now that the evolution of several brachiopod genera is known in detail, it is possible to correlate the shelly deposits with the standard section at Llandovery.

Animal communities have been defined for this period, and they have been shown to reflect the depth of the sea. These communities are diachronous, and migrated as the transgression advanced.

The twin concepts, of evolving lineages as a basis for correlation and of animal communities as a basis for interpreting the environment, provide the foundation of this work.

BASIS OF CORRELATION

The type section of the Llandovery is to be seen south-east of the town of this name in Wales (Jones 1925). Brachiopods are the dominant faunal element in the area, but correlation of other shelly areas with the type section has had to await the study of the commoner brachiopod lineages. This approach contrasts with the tendency for workers in the shelf areas to have correlated Silurian beds by the assemblages of species present.

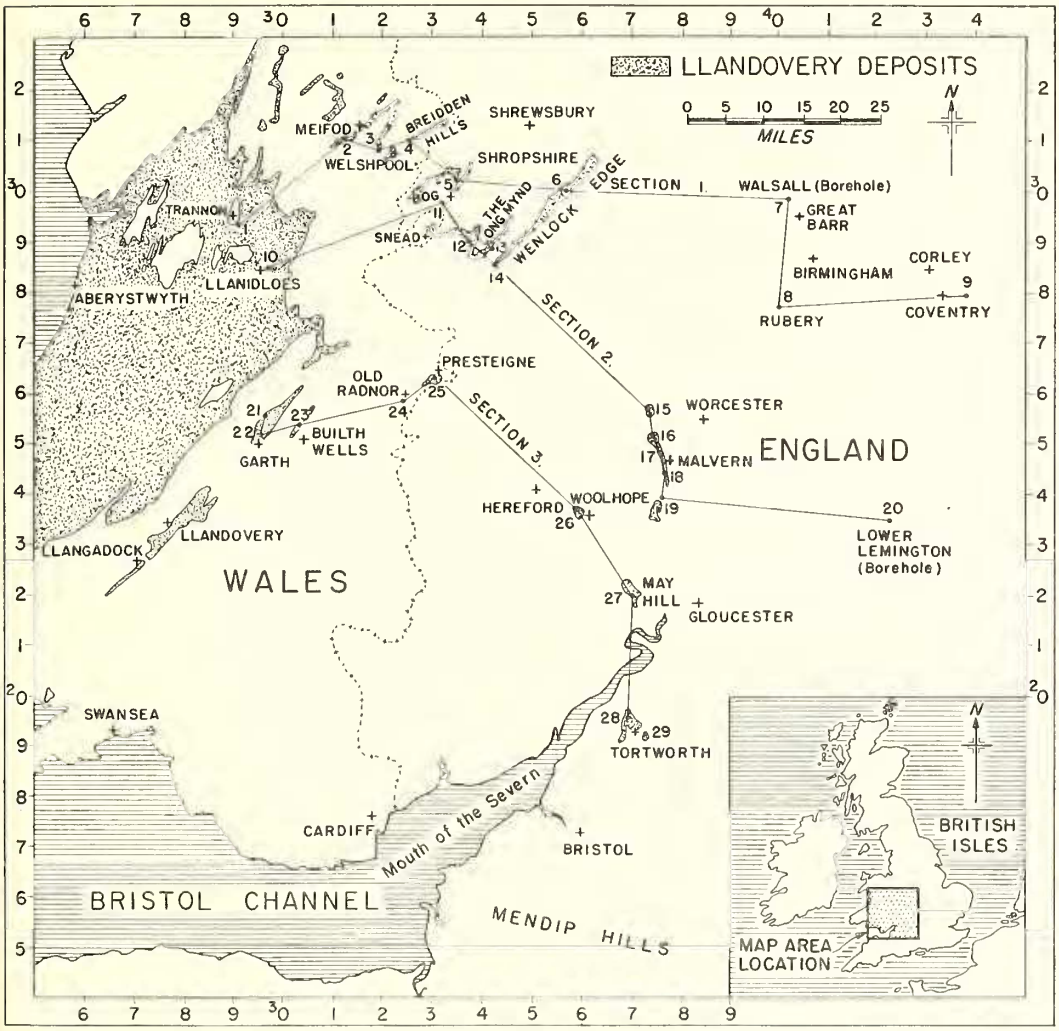
Evolutionary sequences are now known for the stricklandiids (Williams 1951, St. Joseph 1935), the pentamerids (St. Joseph 1938), the atrypide *Eocoelia* (Ziegler 1966*b*) and the strophomenide *Leptostrophia* (Cocks 1967*a*).

Some brachiopod lineages and their relationship with the type Llandovery are shown in text-fig. 2. The only brachiopods on this list which do not occur at Llandovery itself are *E. sulcata*, *C. lirata typica*, and *Pentameroides*; their assignment to C_6 is based on the fact that they are known to occur between C_5 and basal Wenlock beds in adjacent areas of the Welsh Borderland.

Most of the Lower Silurian of the British Isles carries a fauna of graptolites. Lapworth (1878) and Elles and Wood (1901–18) established a sequence of graptolite zones which

[Palaeontology, Vol. 11, Part 5, 1968, pp. 736–82.]

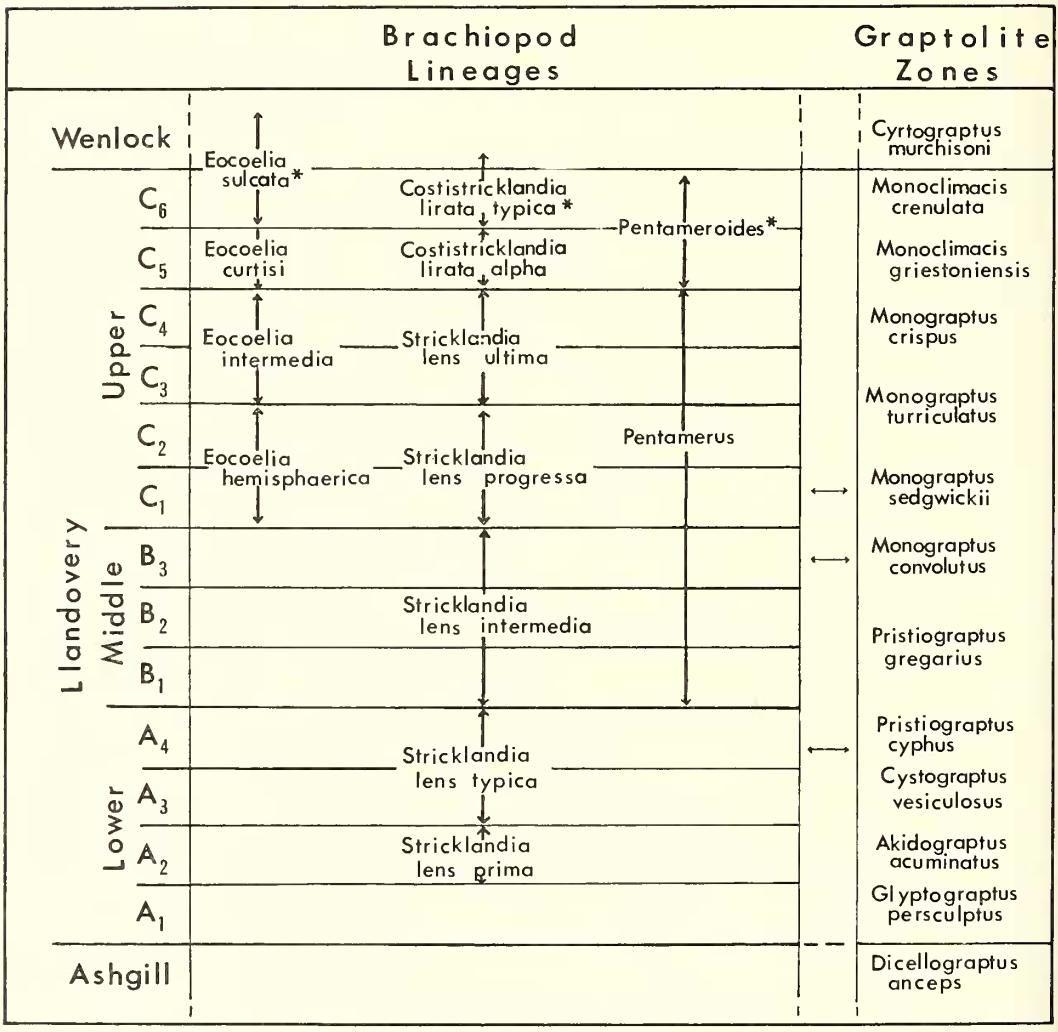
have provided an accepted basis for correlation. A few graptolites of zonal value have been found at Llandovery (text-fig. 2) but are only recorded from three horizons. Jones (1925, p. 360) found graptolites referable to his *acinaces* Zone in A_4 (this is now equated with the lower part of the *cyphus* Zone—Toghill 1968): Jones also (1949, p. 52) cor-



TEXT-FIG. 1. Location map of the Llandovery rocks of Wales and the Welsh Borderland, showing traverse lines and position of local sections.

relates B_3 with the *C. cometa* Band, which is in the upper part of the *convolutus* Zone; and he further records graptolites of the *sedgwickii* Zone (1925, p. 370) from beds assigned to C_1. This last fauna has been confirmed by our recent collecting from the other known locality of this restricted facies near an old ford across the River Sefin (Grid Ref. SN/7419 2811).

In addition to these finds from Llandovery itself, other links between the brachiopod and graptolite sequences have been determined in the upper half of the Llandovery of Shropshire (Cocks and Rickards, in press); but, as yet, firm ties are not proved for the whole Llandovery succession.



TEXT-FIG. 2. The correlation of brachiopod lineages and graptolite zones with the standard sequence at Llandovery. The asterisks against some brachiopods indicate that they have not been found at Llandovery; the tie-arrows indicate graptolite finds at Llandovery.

The limits of the Llandovery Series at Llandovery have not yet been properly defined, nor have they been firmly correlated with the sequence of graptolites. However, in this paper, we take the base of the series as equivalent to the base of the *Glyptograptus persculptus* Zone, and the top of the series at the base of the Wenlock; or as equivalent

to the base of the *C. murchisoni* Zone, in the sense of Elles and Wood (1901–18). This last zone is sometimes now divided into a lower *Cyrtograptus centrifugus* Zone and an upper, restricted, *C. murchisoni* Zone.

DISTRIBUTION OF ANIMAL COMMUNITIES

By means of large collections from single beds (many with over a thousand specimens), it is possible to quantify the proportions of species present at each locality.

Five main benthic animal communities have been defined by this means from the Llandovery (Ziegler 1965, Cocks 1967*b*, Ziegler, Cocks, and Bambach 1968). Each community is characterized by a particular faunal assemblage, consisting chiefly of brachiopods, and each has been named after a prominent brachiopod genus in the assemblage. They are the *Lingula* Community, the *Eocoelia* Community, the *Pentamerus* Community, the *Stricklandia* Community, and the *Clorinda* Community. At any one time, they occurred in this sequence, from the inferred coastline to the outer margin of the shelf. In beds of C_5 and C_6 age, *Peutamerus* and *Stricklandia* have evolved into *Pentameroides* and *Costistricklandia* respectively, and the community names change correspondingly.

So far the communities have been described only from the Upper Llandovery, but, apart from *Eocoelia*, the characteristic genera also occur in the Middle Llandovery, and the *Stricklandia* and *Clorinda* Communities are present in Lower Llandovery beds. A *Cryptothyrella* Community occurs in the Lower and Middle Llandovery with associates of the *Eocoelia* Community, and it appears to be an early equivalent of the latter community; it is abundant in basal beds at several areas, and occurs also in North America (Ziegler and Boucot, in press).

In addition, during parts of the Middle and Upper Llandovery, the position of the *Eocoelia* Community in Shropshire is taken by the parallel ? *Rostricellula* Community (Cocks and Rickards, in press). Also, in places near the edge of the shelf, the *Clorinda* Community dwindles to a sparser 'Marginal *Clorinda*' Community, with many typical members absent.

Apart from the burrowing *Lingula*, all the Llandovery brachiopods were epifaunal. Thus the majority of Silurian level bottom communities contrast with equivalent modern communities which are mainly infaunal. These Silurian communities were therefore less dependent on the type of substrate than their modern counterparts.

Rocky bottom communities are known at the base of some local sequences, although in all cases where these have been preserved they are accompanied by some soft-bottom elements.

The distribution of the main communities at three horizons in the Llandovery is shown in three maps at the end of the paper (text-figs. 12–14). While the actual depths represented by the communities are uncertain, the lines bounding them are presumed to parallel the bathymetric contours. Thus we have a picture of the changing configuration of the shelf sea during the transgression, and of the migration of the communities with time.

A distinction is drawn between 'basin' and 'graptolitic' facies. The former is restricted to areas (for example text-fig. 3, cols. 1 and 10) where rapid sediment supply, great

water depths, and considerable subsidence has resulted in large thicknesses of sediment. The term 'graptolitic' facies is used for rocks in which the dominant fossils are graptolites, and in which shelly forms, apart from a few orthocones and epiplanktonic bivalves, are generally absent. This facies represents one or other of two environments, firstly deposition under water which was too deep for benthic colonization at that time, or, secondly, water of any depth which had a foul bottom, lower temperature, or other physical conditions inimical to a shelly fauna. When a graptolitic facies occurs to seaward of a *Clorinda* Community, we feel justified in selecting the first of these alternatives, and interpreting the occurrence as being too deep for a shelly fauna; this situation applies to all of the Llandovery in the Welsh Borderland. However the second alternative certainly applied at other times and places during the Lower Palaeozoic, for example this is how we would interpret the Wenlock Shale to the south of the Long Mynd, Shropshire.

Acknowledgements. We are indebted to the late Professor W. F. Whittard for his advice, fossil collections, and loan of field maps. Dr. M. L. K. Curtis kindly made his thesis and collections available, and conducted us to localities in the Tortworth Inlier. Drs. W. B. N. Berry, R. B. Rickards, and P. Toghill identified the graptolites we have found, and discussed older records.

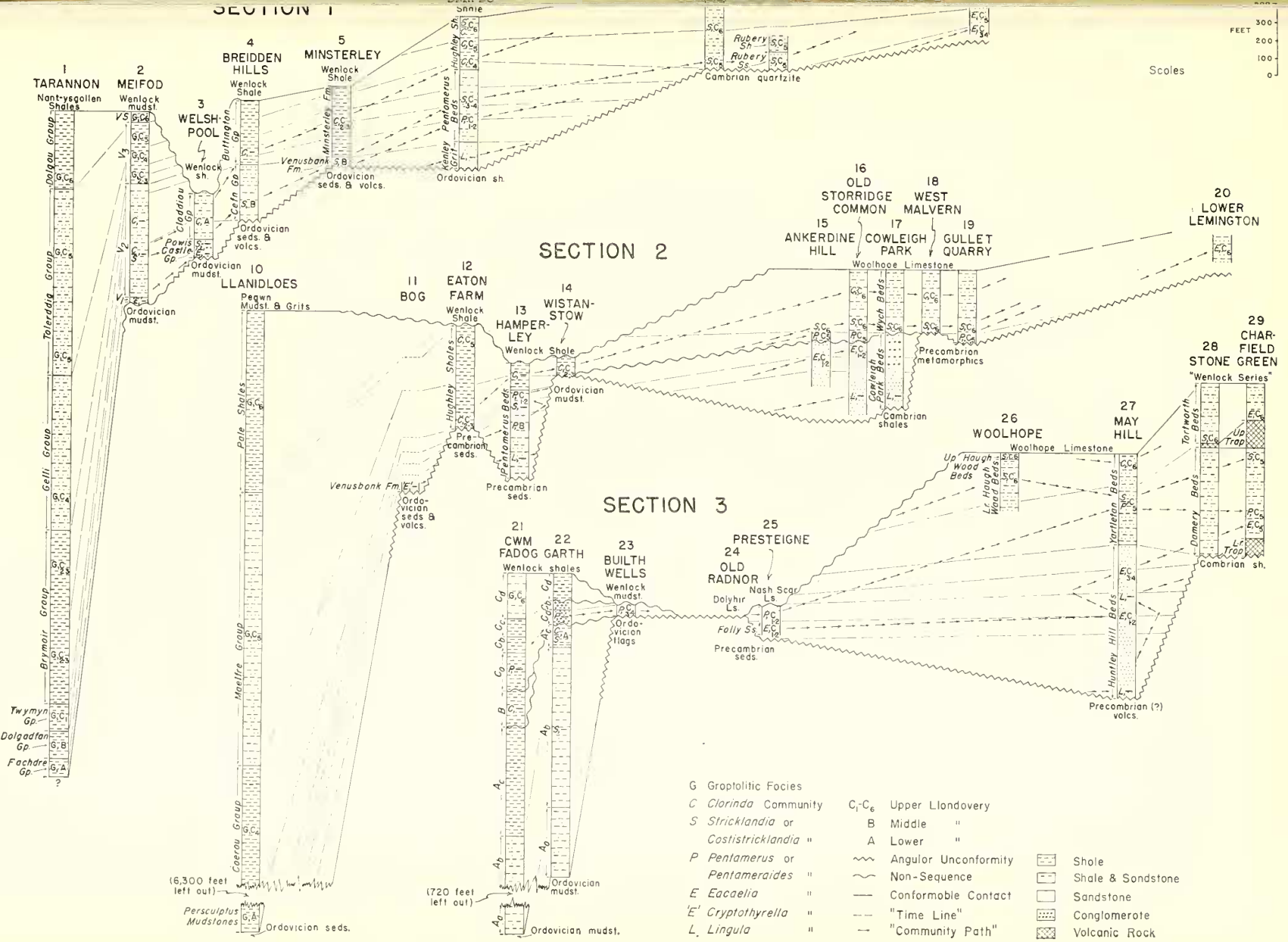
The theses by Ziegler (1963) and Cocks (1965), both at Oxford, were supported in part by the Burdett-Coutts Fund and the Department of Scientific and Industrial Research respectively. We are grateful to Mr. J. M. Edmonds and Mr. H. P. Powell for housing our thesis collections in the Oxford University Museum (Appendix 1), and for providing funds for their labelling. Collections made subsequently are deposited in the British Museum (Natural History) (Appendix 2) and the U.S. National Museum (Appendix 3). These last were prepared by Ziegler in the laboratories of Dr. A. J. Boucot at the California Institute of Technology from 1964–6. More recently, Ziegler has been supported by Grant 910–G from the Petroleum Research Fund, administered by the American Chemical Society; and by Grant GB–6592 from the National Science Foundation of America.

DESCRIPTIONS OF THE OUTCROPS

Three traverses across part of Wales and the Borderland (text-fig. 1) are represented by the composite sections in text-fig. 3.

In the following account, the areas studied in detail are treated first; i.e. the sections from Minsterley to Tortworth (text-fig. 3, cols. 5–6, 11–19, and 25–9). These constitute the classical Welsh Borderland area. Secondly, we discuss the small inliers to the east of the Borderland (text-fig. 3, cols. 7–9 and 20). We have examined collections from these areas, and include them for the sake of completeness. Finally we contrast these shelf sequences with areas to the west of the Borderland, which in Llandovery times formed the shelf margin and the basin. These areas are mostly in Wales (text-fig. 3, cols. 1–4, 10, and 21–3); we have collected in all of them, with the exception of the purely graptolitic sequences.

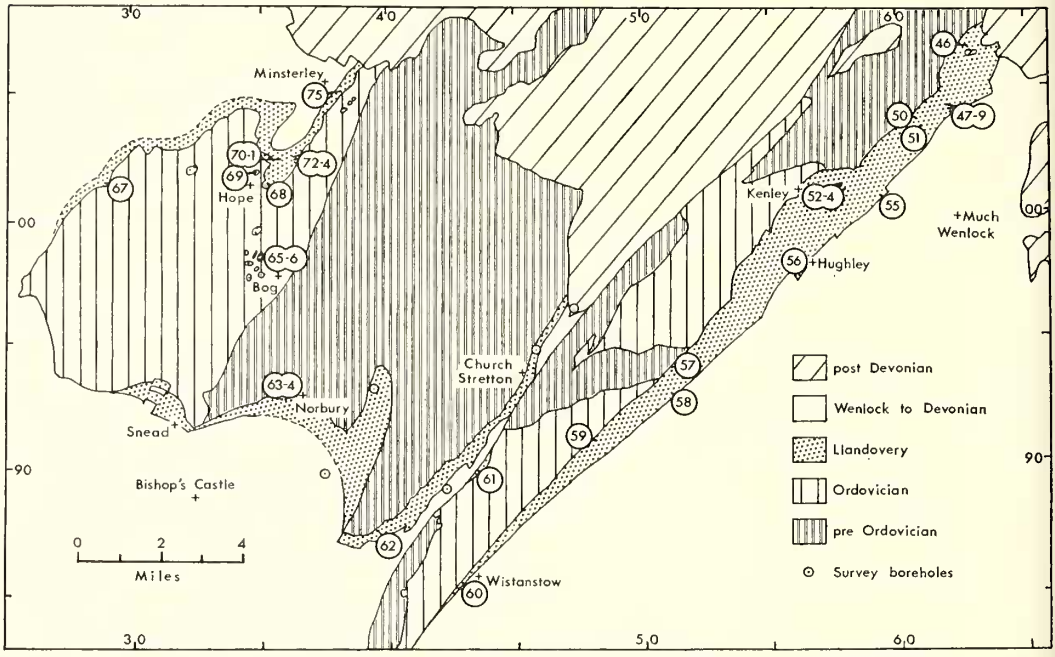
TEXT-FIG. 3. Three traverses across the Welsh Borderland (see text-fig. 1) showing local sections with communities, correlation, lithology, and stratigraphical relationships. True thicknesses are shown. The distances between columns are not the straight-line distances, but the N. 60° W. component of these distances.


SECTION 1
SECTION 2
SECTION 3
1 TARANNON
Nant-ysgollen Shales
2 MEIFOD
Wenlock mudst.
3 WELSH POOL
Wenlock sh.
4 BREIDDEN HILLS
Wenlock Shale
5 MINSTERLEY
Wenlock Shale
Minsterley Fm
Venusbank Fm
Ordovician seds. & volcs.
Ordovician sh.
Hughley Sh
Pentamerus Beds
Kenley Grit
Snnie
Rubery Sh
Rubery
Cambrian quartzite
Scoles
FEET
300
200
100
0
Dolgau Group
Tolerddia Group
Gelli Group
Brymoir Group
Twymyn Gp.
Dolgadfan Gp.
Fachdre Gp.
Buttington Gp.
Cefn Gp.
Cloddiau Gp.
Powis Castle Gp.
Ordovician mudst.
Ordovician seds. & volcs.
10 LLANIDLOES
Pegwn Mudst. & Grits
Porfe Shales
Moelfre Group
Caerau Group
Persculptus Mudstones
Ordovician seds.
(6,300 feet left out)
11 BOG
12 EATON FARM
Wenlock Shale
Shales
Hughley
Pentamerus Beds
Pre-cambrian seds.
13 HAMPER-LEY
14 WISTAN-STOW
Wenlock Shale
Ordovician mudst.
Precambrian seds.
Venusbank Fm
Ordo-vician seds & volcs.
16 OLD STORRIDGE COMMON
15 ANKERDINE HILL
17 COWLEIGH PARK
18 WEST MALVERN
19 GULLET QUARRY
Woolhope Limestone
Wych Beds
Cowleigh Park Beds
Precambrian metamorphics
Cambrian shales
20 LOWER LEMINGTON
26 WOOLHOPE
Woolhope Limestone
Up Hough Wood Beds
Lr Hough Wood Beds
27 MAY HILL
Yartleton Beds
Hunley Hill Beds
Precambrian (?) volcs.
28 STONE
29 CHAR-FIELD GREEN
"Wenlock Series"
Tortworth Beds
Damery Beds
Up Trap
Lr Trap
Cambrian sh.
21 CWM FADOG
22 GARTH
Wenlock shales
23 BUILTH WELLS
Wenlock mudst.
Ordo-vician flags
24 OLD RADNOR
25 PRESTEIGNE
Dolyhir Ls.
Nash Scar Ls.
Folly Ss.
Precambrian seds.
(720 feet left out)
Ordovician mudst.
G Graptolitic Facies
C Clorinda Community
S Stricklandia or Costistricklandia "
P Pentamerus or Pentameraides "
E Eocoelia "
'E' Cryptothyrella "
L Lingula "
C1-C6 Upper Llandovery
B Middle "
A Lower "
Angulor Unconformity
Non-Sequence
Conformoble Contact
"Time Line"
"Community Path"
Shole
Shale & Sondstone
Sandstone
Conglomerote
Volcanic Rock

MINSTERLEY AND BOG

Text-fig. 3, cols. 5 and 11

Exposures of Llandovery sediments to the north and west of the Shelve Inlier, Shropshire (text-fig. 4), occur in a sinuous strip running north-east from north of Chirbury through Hope Valley and Venusbank to near Minsterley. Various outliers, including



TEXT-FIG. 4. Locality map of Shropshire (after many authors, with modifications).

those at Bog, rest unconformably on the Ordovician of the Shelve Inlier. The area has been re-mapped, but the only major re-interpretation is based on new exposures indicating that the Venusbank 'outlier' is connected northwards with the outcrop in Hope Valley.

Whittard (1932) used the same stratigraphical names, i.e. Pentamerus Beds and Purple Shale, throughout Shropshire, but the Llandovery rocks of the Minsterley and Bog area differ in lithology and age from the beds in the Wenlock Edge outcrop (see below). Accordingly we propose new names: the Bog Quartzite, Venusbank Formation, and Minsterley Formation.

(*a*) *Venusbank Formation and Bog Quartzite*. The type section of the Venusbank Formation is in Hope Brook, running eastwards from near Hope Quarry. The base is exposed in both brook (SJ/3554 0207) and quarry (SJ/3550 0207), where a sandstone with occasional shale fragments rests on Hope Shales of Ordovician (Llanvirn) age. The top of the Formation in Hope Brook is taken above the highest of the dominant sandstones (SJ/3572 0215).

The base of the formation may also be seen in an outlier (SJ/3458 0146) two-thirds of a mile south-west of Hope Quarry (Tyler 1925). Here a basal conglomerate is present, in which pebbles (up to 5 cm.) of Hope Shales, Stapeley Volcanics (Llanvirn) and Stiperstones Quartzite (Arenig) occur. This outlier occurs at 900 ft. O.D. (Ordnance Datum—feet above sea level) but another small outlier is present 150 yards to the east, on the side of the valley and between 650 and 700 ft. O.D.; Hope Quarry lies at 600 ft. O.D., and, to the south-east, the Llandovery at Venusbank (SJ/3535 0125) is at 800 ft. O.D. Thus the conclusions reached by Whittard (1932, pp. 893–5), of an irregular base to the Llandovery of the area, are confirmed; steep dips are absent and there is no detectable subsequent faulting. It appears that the present-day Hope Valley has been re-excavated along the line of a pre-Middle Llandovery depression, and that the Llandovery sea spread over a surface relief of 200–300 ft. in this area. The thickness of the Venusbank Formation varies between 0 and 200 ft. (0–65 m.).

The formation is well exposed at Hope Quarry (SJ/3550 0207), where a thickness of 30 ft. (10 m.) is visible. Sandstone bands up to 3 ft. (1 m.) thick occur there, sometimes including shells or mudflakes at or near their base, with each unit fining up into unfossiliferous silts. Some of the sandstones have parallel laminae throughout, but cross-bedding is absent, apart from very occasional ripple cross-lamination on the tops of one or two sandstones. Unit bases are sharp, with no visible bottom structures apart from worm traces. Low-angle channelling occurs with occasional silty partings at the base of the channelling sandstone. These sediments may represent proximal turbidites filling a previously scoured channel of *Pentamerus*- and *Stricklandia*-Community depth.

The Llandovery also rests unconformably on the Ordovician in some poorly exposed outliers near Bog (SO/355 979) and at Round Hill (SO/348 993). Many large loose blocks of coarse quartzite are present; often containing pebbles and shale chips. These beds are termed the Bog Quartzite.

Fossil communities. The Hope Valley sections of the Venusbank Formation have mainly yielded fossils of the *Stricklandia* Community (Locs. 68–70, 72, 73); the exceptions are the presence of *Pentamerus* Communities at some places near the base of the formation (Loc. 74 and at SJ/3555 0107). This suggests that the irregular landscape was covered by a moderately deep shelf sea (*Pentamerus* Community) that soon became slightly deeper (*Stricklandia* Community). However, there may have been some fluctuation in depth, as Whittard (1932, p. 876) reports *Pentamerus* above *Stricklandia*-bearing beds in Hope Quarry.

In Ox Wood Dingle (Loc. 67), 4 miles west of Hope Valley, the *Stricklandia* Community is also present. However, early shallow-water conditions may be indicated at The Stubbs (2 miles north-west of Hope Quarry—SJ/324 033) where Whittard records (1932, p. 874) *Lingula* in growth position near the base of the Venusbank Formation.

The fauna of the Bog Quartzite (Locs. 65, 66) is a mixture of a near-shore *Cryptothyrella* Community with some rocky-bottom elements (Ziegler, Cocks, and Bambach 1968).

Correlation. All the collections from the Venusbank Formation and Bog Quartzite have yielded *Stricklandia*; the subspecies present at Bog is *S. lens intermedia* indicating a

Middle Llandovery age; the subspecies from the Venusbank Formation is at the boundary between *S. lens intermedia* and *progressa* and is B_3 to C_1 in age. A collection from near the base of Hope Quarry (Loc. 70) includes the graptolite *Climacograptus* aff. *rectangularis* (identified by R. B. Rickards), which indicates a Middle Llandovery age for the lower part of the formation. Whittard (1932, facing p. 896) records *Monograptus runcinatus pertinax* from the 'Pentamerus Beds of the Wilmington-Minsterley' area; this suggests that at least some of the Venusbank Formation is of early Upper Llandovery age.

(*b*) *Minsterley Formation*. The type section goes diagonally across the strike of the formation and is in Hope Brook. The base is taken above the top sandstone of the Venusbank Formation (SJ/3572 0215), and the top above the last purplish bed in the exposure to the south of Wagbeach (SJ/3642 0270). The thickness of the Minsterley Formation is about 400 ft.

The lowest beds seen are calcareous siltstones and mudstones, with occasional coarser beds; these represent a distinct sedimentary environment unknown elsewhere in the Welsh Borderland. They pass up into maroon, green, or blue mudstones, the top 150 ft. (49 m.) being of the same dominantly purple colour as the Hughley (Purple) Shales on the main Wenlock Edge outcrop. The mudstones contain some interbedded siltstone and bands of fragmented shells. Locally, the Minsterley Formation overlaps the Venusbank Formation, e.g. at Estell (Whittard 1932, p. 877) and east of Minsterley; in these areas the formation tends to be coarser. The Minsterley Formation is followed by several hundred feet of unfossiliferous turbidites, well exposed in Hope Valley, which may be either late Llandovery or early Wenlock in age.

Fossil communities. Collections in Hope Brook (Loc. 71) and Minsterley-Habberley Lane (Loc. 75) are both in the *Clorinda* Community; this indicates that the Minsterley Formation was deposited in deeper water than the underlying Venusbank Formation.

Correlation. The brachiopods collected from the Minsterley Formation provide no precise evidence of age, but Whittard's (1932, p. 877) record of graptolites from Locality 75 includes *Monograptus halli*, *M. becki*, and *M. cf. proteus*. This assemblage indicates a *turriculatus* Zone age (Cocks and Rickards, in press). A lack of fossils in the upper part of the formation, and in the overlying turbidites, makes it uncertain whether it terminates, even approximately, at the end of Llandovery time.

NORBURY AND CHURCH STRETTON

Text-fig. 3, cols. 12 and 13

A long winding outcrop of Llandovery rocks borders the south side of the Cambrian and Ordovician rocks of the Shelve Inlier, and continues all around the southern part of the Pre-Cambrian rocks of the Long Mynd (text-fig. 4). The formation names which we use for this area are the same as those used by Greig *et al.* (1968); the Pentamerus Beds and the Hughley (or Purple) Shales. The area, sometimes termed the southern Long Mynd-Shelve Outcrop, was mapped by Whittard (1932, pl. 59, 60) and more recently by the Geological Survey (Church Stretton Sheet, New Series, no. 166). Six

boreholes were drilled to assist the Survey in their mapping, and four of these passed through beds of Llandovery age (Cocks and Rickards, in press). These are called the Eaton Farm (text-fig. 3, col. 12) and Robury Ring Boreholes, both of which are to the west of the southern Long Mynd spur, and the Hamperley (text-fig. 3, col. 13) and Springbank Farm Boreholes, both of which are to the east of the Long Mynd spur and in the Church Stretton Valley. A fifth borehole, at Botvyle (also shown on text-fig. 4), did not penetrate to the local base of the Wenlock.

(*a*) *Pentamerus Beds*. Between Plowden (SO/382 874) and Little Stretton (SO/445 921), up to 60 ft. (20 m.) of conglomerates are intermittently present below mudstones and other sediments with *Pentamerus*. These beds, when fossiliferous, contain a *Lingula* Community, and, in parts, the formation name Kenley Grit (used in the adjacent Wenlock Edge outcrop—see below) might be employed. However, as the conglomerates fill quite small topographic pockets, and locally vary both in lithology and possible age, we follow Whittard (1932) and the Geological Survey (Greig *et al.* 1968) in treating these beds as a local coarse base to the Pentamerus Beds. The Hamperley and Springbank Farm Boreholes both revealed complete sections through the Pentamerus Beds, which are 480 (157 m.) and 170 ft. (56 m.) thick in the respective cores (although these thicknesses may be affected by minor faulting).

Whittard (1932) interpreted the basal deposits to the south of the Long Mynd as a beach with sea stacks. However, from faunal and sedimentological considerations, it seems more probable that most of the sedimentation occurred sub-tidally, and certainly a fairly deep-water *Pentamerus* Community was established at Hillend Farm (Loc. 62), only 20 ft. (7 m.) above the unconformity with the Pre-Cambrian.

The Pentamerus Beds are absent in the large embayment to the west of the southern Long Mynd spur (text-fig. 3, col. 12) and also south of The Roveries (SO/323 915); at both places Hughley Shale rests directly upon the unconformity. However, between these two places, at Norbury (Locs. 63 and 64), a local lens of calcareous sandstone, often crowded with *Pentamerus*, is present between the unconformity and the Hughley Shale, and this lens is termed 'Pentamerus Beds'. Further west, near Snead, Whittard (1932, p. 871) recorded 280 ft. of Pentamerus Beds, but his description shows that the lowest Silurian rocks contain a limited shelly fauna, perhaps representing an environment deeper than the *Clorinda* Community.

Fossil Communities. In the Hamperley Borehole, the *Lingula* Community is present between 65 and 115 ft. (21–38 m.) above the base (Cocks and Rickards, in press). This is followed by a ?*Rostricellula* Community, which is a parallel community to that of *Eocoelia*, and occupies a similar position, between *Lingula* and *Pentamerus* Communities. In the borehole, a *Pentamerus* Community succeeds the ?*Rostricellula* Community, and is itself succeeded by a *Stricklandia* Community. After the *Stricklandia* Community, there was a reversion to the *Pentamerus* Community immediately below the Hughley Shales. In the Springbank Farm Borehole, the Pentamerus Beds carry a *Pentamerus* Community throughout, although at approximately two-thirds up the formation, the proportion of *Stricklandia* increases enough to be termed a *Pentamerus*/*Stricklandia* mixture for that part of the core. This mixture was probably contemporary with the *Stricklandia* Community in the Hamperley Borehole.

In the surface exposures, the *Lingula* Community is developed in various parts of the basal coarse facies. At Marshbrook (Loc. 61) we have collected a mixed *Lingula*/?*Rostricellula* Community. ?*Rostricellula* is a close homeomorph of *Eocoelia* and was listed as the latter by Whittard (1932, p. 864). *Pentamerus* Communities occur at Hillend Farm (Loc. 62) and at Norbury (Locs. 63 and 64). Further to the west, deeper water was present near Snead; above a basal *Pentamerus* Community, Whittard (1932, p. 872) records a fauna which we interpret as a 'Marginal' *Clorinda* Community.

Correlation. Graptolites from the Hamperley Borehole indicate the *convolutus* Zone for the middle part of the formation, with the *sedgwickii* Zone above. The *sedgwickii* Zone is also proved for the middle of the Springbank Farm core. The brachiopod collections from Hillend Farm and Norbury both contain *Eocoelia*, but the former locality carries *E. hemisphaerica* (indicating C_{1-2} age), while at Norbury *E. intermedia* is present (Ziegler 1966*b*), and indicates a C_{3-4} age for beds near the local base of the formation.

Whittard (1932, p. 872) records *Climacograptus* sp., *Monograptus halli* and *M. dextrorsus* from Snead; these indicate the *turriculatus* Zone. This evidence, together with Whittard's statement (1932, p. 873) that 'there is a gradation along strike from arenaceous to argillaceous sediments', points to a fairly rapid increase in depth westwards from the Long Mynd during C_{3-4} times. It also emphasizes that both base and top of the Pentamerus Beds are diachronous.

(*b*) *Hughley* (*or Purple*) *Shales.* These beds are not well exposed south of the Longmynd-Shelve Inlier. The Hamperley Borehole shows a thickness of 150 ft. (49 m.) and Whittard (1932, p. 866) estimated a thickness of 200–30 ft. of Hughley Shales to the south of the Long Mynd. To the west of the Long Mynd spur there is a greater thickness; 560 ft. (184 m.) is seen in the Eaton Farm borehole, although small faults may have affected this figure. Still further west, near Snead, Whittard (1932, p. 871) estimated that a minimum of 250 ft. were present. The formation is distinguished from the underlying Pentamerus Beds and overlying Wenlock Shale mainly by its colour, which is a characteristic maroon or purple, although green and brown bands also occur. The Pentamerus Beds are usually blue-hearted mudstones, and the Wenlock Shale grey and slightly siltier. The contacts between the formations are usually sharp.

Fossil Communities. Whittard (1932, p. 869) reports a *Clorinda* Community fauna between Plowden and Minton, and this community is also present in the Eaton Farm, Robury Ring, Hamperley, and Springbank Farm Boreholes. Above the *Clorinda* Community in the two boreholes to the west of the southern Long Mynd spur, a 'Marginal' *Clorinda* Community occurs, which probably indicates (Cocks and Rickards, in press) a continued deepening of the sea.

Correlation. Graptolites from the boreholes show a sequence from within the *turriculatus* Zone, through the *crispus* Zone and into the *griestoniensis* Zone. The top 75 ft. (25 m.) of the Hughley Shale in the Eaton Farm Borehole are above the *griestoniensis* Zone, but carry no diagnostic graptolites. Thus the presence or absence of the highest Llandovery *crenulata* Zone is not yet confirmed.

WENLOCK EDGE

Text-fig. 3, cols. 6 and 14

Llandovery rocks crop out in a strip twenty miles long, which parallels, and directly underlies, the rocks of Wenlock Edge (text-fig. 4). Whittard (1928) described this 'Main' outcrop in detail; the three formation names which he used, i.e. Arenaceous Beds, *Pentamerus* Beds, and Purple Shales, have been subsequently named by the Geological Survey Kenley Grit, Pentamerus Beds, and Hughley Shales. The northern part of this area was covered by the Shrewsbury Memoir (Pocock *et al.* 1938), and the southern part by the Church Stretton Memoir (Grieg *et al.* 1968). A recent revision of the northernmost part of the area was prompted by a very large temporary exposure at Devil's Dingle (Cocks and Walton 1968).

(*a*) *Kenley Grit.* A maximum thickness of 200 ft. (65 m.) is reached near Kenley itself (SJ/558 004). Four-and-a-half miles to the south-west, the Kenley Grit dies out near Gretton (SO/519 946). To the north-east, it thins more gradually, and is 35 ft. (11 m.) thick in Harper's Dingle (SJ/634 072), near the point where the Llandovery is covered by the Carboniferous, 6 miles from Kenley.

The formation consists of conglomerates, sandstones, arkoses, and some finer beds, but to the north-east there is no conglomerate except at the base; these basal pebbles are mainly derived from Uriconian rocks, but occasional Cambrian and Ordovician pebbles are present (Whittard 1928, p. 740). The formation rests with strong unconformity upon Ordovician and older rocks, and is distinguished from the overlying Pentamerus Beds by the abundance of coarse clastics and the absence of calcareous beds.

Fossil communities. The fossils recorded from the Grit (Whittard 1928, p. 741) all belong to the *Lingula* Community. *Lingula* itself occurs near the top of the formation at Morrellswood (near Loc. 46) and Sheinton Brook (near Loc. 50); it is also present in an old quarry near Kenley (Pocock *et al.* 1938, p. 106). An assemblage with abundant rhynchonellides, referable to the *Lingula* Community, but without *Lingula* itself, occurs at Cressage Park, two miles east of Kenley (Whittard 1928, p. 741).

Correlation. No fossils found in the Grit are of zonal significance; however, at Morrellswood (Loc. 46), beds of C_{2-3} age occur immediately above the Grit, which must therefore be earlier.

(*b*) *Pentamerus Beds.* The Kenley Grit passes up gradationally into the Pentamerus Beds, but to the south-west, where the Grit is absent, the Pentamerus Beds rest unconformably upon Uriconian, Tremadoc, and Ordovician rocks. The Pentamerus Beds reach a maximum thickness of between 400 and 500 ft. (about 150 m.) in the north-eastern half of the area, and thin southwards to nothing in the vicinity of Wistanstow (SO/431 857). A *Pentamerus*-bearing conglomerate 1 in. thick has been reported (Whittard 1928, p. 749) in the bed of the Onny River (Loc. 60), but it is absent higher up on the river bank, where Hughley Shales rest directly upon the Ordovician. The lithology of the Pentamerus Beds consists of blue mudstones, with sporadic shelly limestones, and less fossiliferous siltstones and concretionary limestones. At the extreme northern end of the outcrop the 'Dingle Conglomerate' is seen near the base of the Pentamerus Beds in Harper's Dingle (SJ/6328 0704); the bed is confined to this one locality, and consists

of pebbles of Uriconian rock and *Pentamerus* shells set in a matrix of quartz sand and calcite (Whittard 1928, p. 745, Pocock *et al.* 1938, p. 107). Apart from this distinctive conglomerate, the Pentamerus Beds may be differentiated from the Kenley Grit by their palaeontology, finer grain size, and more calcareous sediments, but the contact between the two formations is gradational. The top of the Pentamerus Beds is usually sharp, with the colour change to the Hughley Shales, but the contact is sometimes confused by the presence of small turbidite bands (e.g. at Sheinton Brook—Loc. 51).

Fossil communities. A collection from near Gilberries (Loc. 57), in the lower part of the Pentamerus Beds, contains abundant *Hyattidina*. This genus does not fit precisely into any of the main Llandovery communities as at present defined (Ziegler *et al.* 1968), but abundant *Hyattidina* are associated with the *Eocoelia* Community in New York State and also at Presteigne (Locs. 90 and 93); we conclude that the Gilberries collection represents an intermediate environment between the *Lingula* Community of the Kenley Grit, and the deeper-water communities of the remainder of the Pentamerus Beds.

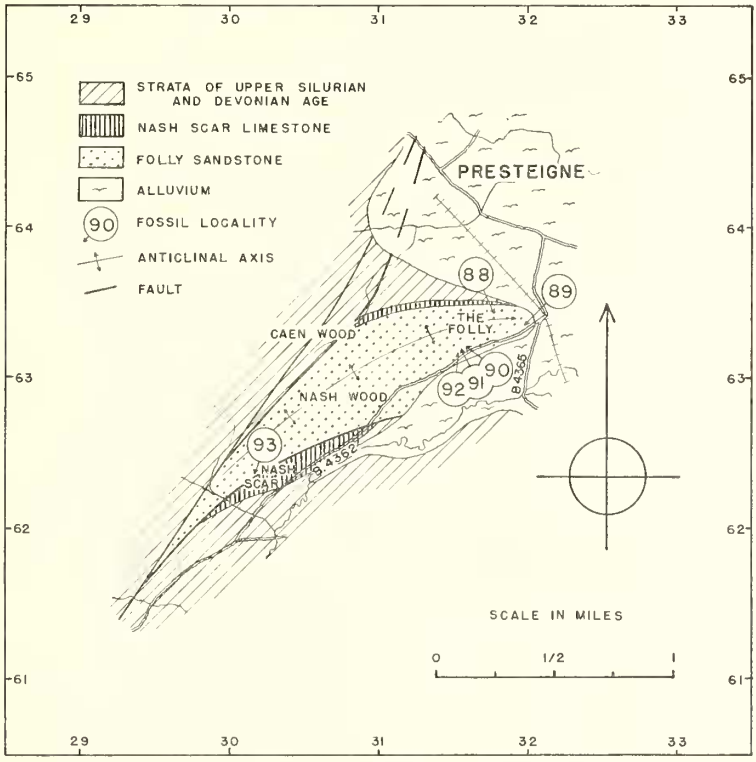
Collections from north-west of Merrishaw (Locs. 52 and 53) and near Ticklerton (Loc. 59) are typical of the *Pentamerus* Community. At about the centre of the outcrop, the deeper-water *Stricklandia* Community is present (Loc. 54) and in Sheinton Brook (Loc. 50), although this last collection only contains 1% of *Stricklandia*. At Morrellswood (Loc. 46) an assemblage dominated by *?Rostricellula* is present, this assemblage also occurs in the Church Stretton area (see above), where it is interpreted as a parallel community to that of *Eocoelia*.

Correlation. Eocoelia hemisphaerica indicates a C_{1-2} age for the *Pentamerus* Communities at Ticklerton (Loc. 59) and Merrishaw (Loc. 52). The *Stricklandia* Community at Sheinton (Loc. 50) and the collection from Merrishaw (Loc. 53) contain *S. lens ultima* of C_{3-4} age. Our evidence is thus consistent with a progressive increase of depth from C_1 to C_4 times during the deposition of the Pentamerus Beds of the Wenlock Edge Outcrop. Graptolites from various parts of the formation (Whittard 1928, Pocock *et al.* 1938) are all attributable to the *turriculatus* Zone, which is equivalent to C_{2-3} times.

(*c*) *Hughley (or Purple) Shales.* This formation has a thickness varying from 0 to 500 ft. (0–175 m.). The lithology is dominantly purplish mudstone, but occasional coarser turbidite bands also occur locally. The basal contact with the Pentamerus Beds is sharp and there is overlap on to the Ordovician to the south-east. North of Much Wenlock there is an apparently conformable upper contact with the Buildwas Beds; Cocks and Rickards (in press) conclude that these basal Wenlock beds may include equivalents of all the Lower Wenlock graptolite zones. However, as one proceeds south-west down the outcrop, the Middle Wenlock overlaps both the Lower Wenlock and the Hughley Shales and comes to rest unconformably on the Ordovician four miles south of the Long Mynd.

Fossil Communities. Most of the collections from the Hughley Shale of the Main Outcrop are typical of the *Clorinda* Community (Locs. 47–9, 51, 55, 56, 58, and 60), which reflects a deeper-water environment than that of the Pentamerus Beds. However, near the top of the formation to the north of the River Severn, Cocks and Walton (1968) describe a *Clorinda*/*Stricklandia* mixture, indicating some slight local shallowing in latest Llandovery times.

Correlation. The oldest brachiopod fauna collected from the Hughley Shale is from the very base of the formation in Sheinton Brook (Loc. 51), where *Eocoelia intermedia* indicates a C_{3-4} age. *E. curtisi*, of C_5 age occurs in collections from Boathouse Coppice (Loc. 49) and Wall-under-Heywood (Loc. 58). *Costistricklandia lirata* and *Eocoelia sulcata* indicates a C_6 age for collections from Boathouse Coppice (Loc. 47), Domas (Loc. 55), and Hughley (Loc. 56), all very near the top of the formation. Thus the brachiopod evidence indicates that the formation spanned the period C_3 to C_6. Graptolites



TEXT-FIG. 5. Locality map of Presteigne, Radnorshire.

from the Onny River (Loc. 60) indicate the *turriculatus* Zone (probably equivalent to C_{2-3}); at several localities in the north-east part of the outcrop the *griestoniensis* Zone has now been proved. This last occurs in conjunction with C_5 indicators such as *Eocoelia curtisi*, and the probable presence of equivalents of the highest Llandovery *crenulata* Zone may be inferred by the presence of the C_6 brachiopods.

PRESTEIGNE

Text-fig. 3, cols. 24 and 25

To the south of Presteigne, Radnorshire, the Upper Llandovery crops out along the B4362 road between Nash Scar and the railway bridge near Corton (text-fig. 5); we propose the name Folly Sandstone for these beds. They are folded in an anticline with

its axis extending west-south-west through The Folly (SO/316 633). These Llandovery beds are overlain by a thin (15–20 ft.—about 6 m.) development of the Nash Scar Limestone to the north; to the south their contact is obscure, and the Folly Sandstone may either dip below or be faulted against the 200 ft. (65 m.) of limestone seen in Nash Scar Quarry. The outcrop is covered by drift east of The Folly, and is cut off by an extension of the Church Stretton Fault to the west of Nash Wood. The only published map of the area is the Geological Survey, Old Series, no. 56, NE. and SE., of more than a century ago; but it shows the Llandovery correctly, except for a possible fault north of Nash Scar quarry. The most recent description of these rocks was published in abstract form by Kirk (1951).

The Folly Sandstone consists of dark sandstones in beds ranging from a few inches to a few feet thick. There are many thin conglomerates with rounded pebbles up to $1\frac{1}{2}$ in. (4 cm.) in diameter. The thickness of the Folly Sandstone is in excess of 100 ft., but its base is not exposed. At Old Radnor, 4 miles to the south-west, this unit is missing altogether and Precambrian conglomerates and mudstones occur unconformably beneath the Dolyhir Limestone, the Old Radnor equivalent of the Nash Scar Limestone (Kirk, 1951, p. 56; Garwood and Goodyear, 1918, pl. vii). On the north side of the Presteigne inlier (SO/3152 6347), the contact with the Nash Scar limestone appears to be a disconformity; over an exposed distance of about 20 ft. the limestone rests on various sandstone beds indicating a relief of about 4 ft.

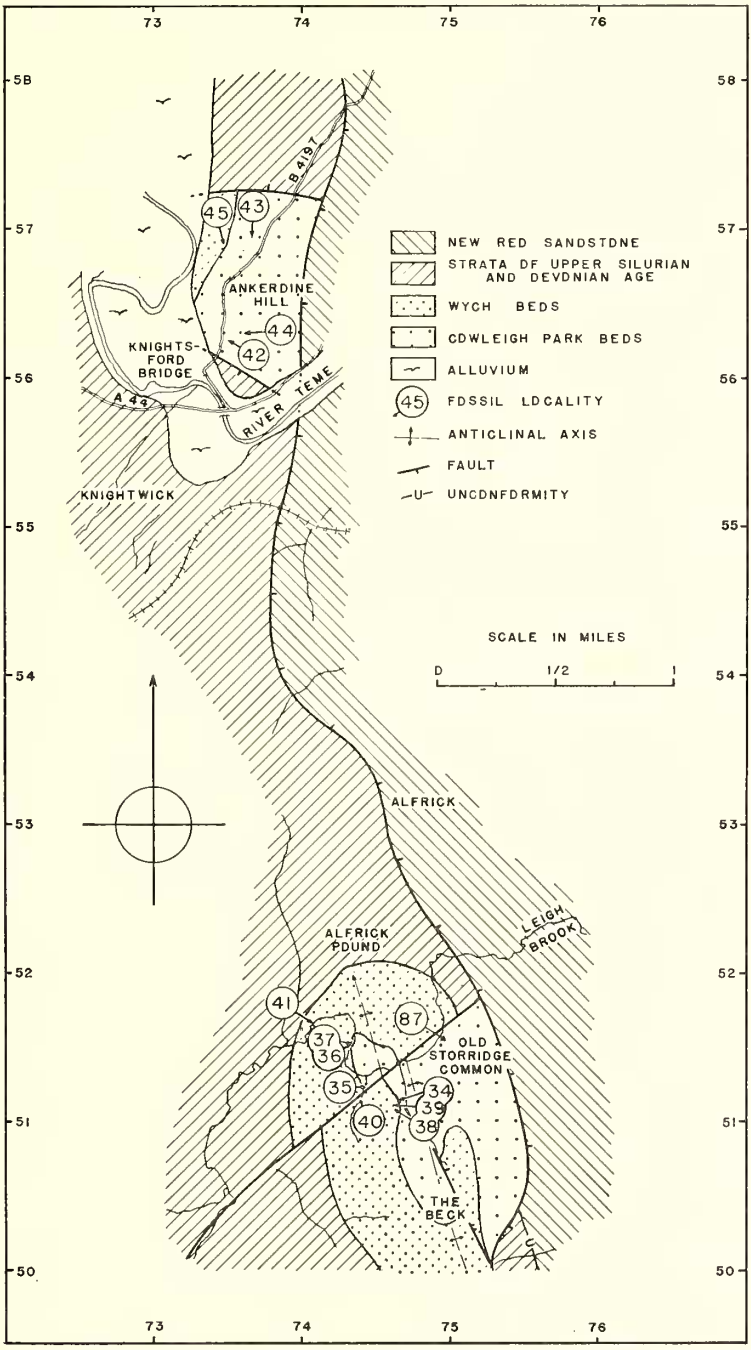
Fossil communities and correlation. The stricklandiids from this area have recently been described by Ziegler (1966*a*). Collections from above Nash Scar quarry (Loc. 93) and from south of The Folly (Loc. 90) yielded *Eocoelia hemisphaerica*; the latter locality also yielded *Stricklandia lens* aff. *progressa*. These collections are both representative of the *Eocoelia* Community and are both C_1–C_2 in age. *Pentamerus* Community collections have been made in the Folly area (Locs. 91 and 92) from higher beds than Locality 90, but the presence of *E. hemisphaerica* shows they are also of C_1–C_2 age. The *Pentamerus* Community is again present in Corton House Quarry (Loc. 89) and in Folly road a few feet under the base of the Nash Scar Limestone (Loc. 88); both these collections contain *S. lens* aff. *progressa* which shows that the top of the Folly Sandstone is still C_1–C_2 in age.

The evidence from the Folly Sandstone shows that the Nash Scar Limestone could be as old as C_3 but the presence of *Rhipidium* (in the Garwood Collection, Geological Survey Museum) proves that part, at least, is Wenlock. An upper age limit is provided by the occurrence of *Cyrtograptus symmetricus* of Wenlock age in the overlying shales (Kirk 1951, p. 56).

ANKERDINE HILL AND OLD STORRIDGE COMMON

Text-fig. 3, cols. 15 and 16

Llandovery beds are exposed in a faulted block at Ankerdine Hill, $6\frac{1}{2}$ miles north of West Malvern, and again in the core of a north-plunging anticline at Old Storridge Common, 3 miles north of West Malvern (text-fig. 6). The base of the Llandovery succession is not exposed in either area. Groom (1910, p. 704) applied the terms, Cowleigh Park Beds, Wych Beds, and Woolhope Shales to the Llandovery rocks of the contiguous Malvern Hills area. However, the term Woolhope Shales is confusing and in any case this relatively thin unit cannot be distinguished with certainty from the Wych Beds.



TEXT-FIG. 6. Locality map of Ankerdine Hill and Old Storridge Common, Worcestershire. This map is continuous with text-fig. 7.

We therefore reject the term Woolhope Shales for these Llandovery beds and regard the Wych Beds as extending up to the first appearance of the dominantly calcareous beds of the Woolhope Limestone. The latter is a gradational contact and could, of course, be diachronous.

(*a*) *Cowleigh Park Beds.* Fine green sandstones and siltstones make up the lowest beds exposed on Ankerdine Hill, while at Old Storridge Common the sediments are coarser and thicker bedded (up to 2 ft.) sandstones. Lack of exposures and the presence of faults make thickness estimates very uncertain; minimum exposed thicknesses are about 200 ft. (65 m.) at Ankerdine Hill and 400 ft. (130 m.) at Old Storridge Common.

Fossil communities. In the Old Storridge Common area, fossils diagnostic of the *Lingula* Community have been recorded by Lamont and Gilbert (1945, p. 642) near the axis of the anticline, and therefore probably low in the Cowleigh Park Beds. The *Eocoelia* Community occurs within a few feet of the top of the formation in Leigh Brook (Loc. 36) and in a north-flowing tributary (Loc. 35). It also occurs in lower beds south of Leigh Brook (Locs. 34 and 87). At Ankerdine Hill, the *Eocoelia* Community is represented in all three collections obtained (Locs. 42–4), but the relative stratigraphic positions of these are not known.

Correlation. All the *Eocoelia* obtained from the Cowleigh Park Beds at Ankerdine Hill and Old Storridge Common are *E. hemisphaerica* of C_1–C_2 age; the type of this species comes from Ankerdine Hill (Ziegler 1966*b*). The lower beds with the *Lingula* Community may either be of a very early Upper Llandovery or a late Middle Landovery age.

(*b*) *Wych Beds.* The Wych Beds consist of shales with some siltstones (less than 10% of the formation). The base is exposed in Leigh Brook (Loc. 37) near the disused Gunwich Mill (SO/7430 5152) west of Old Storridge Common. The contact is sharp, but, although there is palaeontological evidence of a non-sequence, there is no sign of erosion of the underlying Cowleigh Park Beds. The formation appears to be about 400 ft. (130 m.) thick in the section west of Gunwich Mill.

Fossil communities. The basal few feet of Wych Beds at Gunwich Mill (Loc. 37) contain a *Pentameroides* Community. The non-sequence at this locality is thus followed by deeper-water conditions than in the *Eocoelia* Community of the Cowleigh Park Beds. The evidence suggests a progressive increase in water depth throughout Upper Llandovery times with a long pause in sedimentation at this locality before the deposition of the finer grained Wych Beds. A *Pentameroides* Community has also been obtained from loose blocks on Ankerdine Hill (Loc. 45) and may represent a similar low horizon in the Wych Beds.

The *Pentameroides* Community is followed by the *Costistricklandia* Community some 10 or 20 ft. (about 5 m.) above the base of the Wych Beds; collections low in the formation were obtained from a track in Coneygore Coppice (Locs. 38, 39) and in a north-flowing tributary of Leigh Brook (Loc. 40) to the south and south-west of Old Storridge Common. A continued increase in the depth of water is indicated by the occurrence of the *Clorinda* Community near the top of the Wych Beds to the north-east of Mousehole Bridge (Loc. 41).

Correlation. The basal Wych Beds at Gunwich Mill contain *Eocoelia curtisi*, showing that these beds are of C_5 age and that the non-sequence covers the whole of C_3 and C_4 time. The collection from Ankerdine Hill also contains *E. curtisi*.

The highest Wych Beds near Mousehole Bridge yield *E. sulcata* of C_6 age. No fossils of C_6 age have been collected on Ankerdine Hill, and it is probable that the higher parts of the Wych Beds have been cut out by faulting.

MALVERN HILLS

Text-fig. 3, cols. 17, 18, and 19

Llandovery rocks crop out continuously from Old Storridge Common south through West Malvern to Herefordshire Beacon (text-fig. 7). They appear again south of Herefordshire Beacon in the area to the east of Eastnor (text-fig. 8). As in the Old Storridge Common area, we recognize two formations, the Wych Beds (named from The Wyche $1\frac{1}{2}$ miles south of West Malvern) and the Cowleigh Park Beds (Cowleigh Park, 1 mile north of West Malvern contains many small exposures of this lower formation). This area has been mapped by Groom (1899, 1900) and by Phipps and Reeve (1967). We differ from these authors in our interpretation of the Llandovery in two main respects: the upper limit of the Wych Beds is taken immediately below the Woolhope Limestone (see above); and we have no doubt that an unconformity is present below the Silurian along the west side of the Malverns (Reading and Poole 1961, 1962, Ziegler 1964). The Cowleigh Park Beds rest on Cambrian shales east of Eastnor and probably again east of Cowleigh Park; to the south-east of Cowleigh Park they are inferred to rest on Malvernian. Between West Malvern and Ragged Stone Hill (at the south end of the Malvern Hills—SO/759365) the Cowleigh Park Beds are overlapped by the Wych Beds which rest directly on the Malvernian.

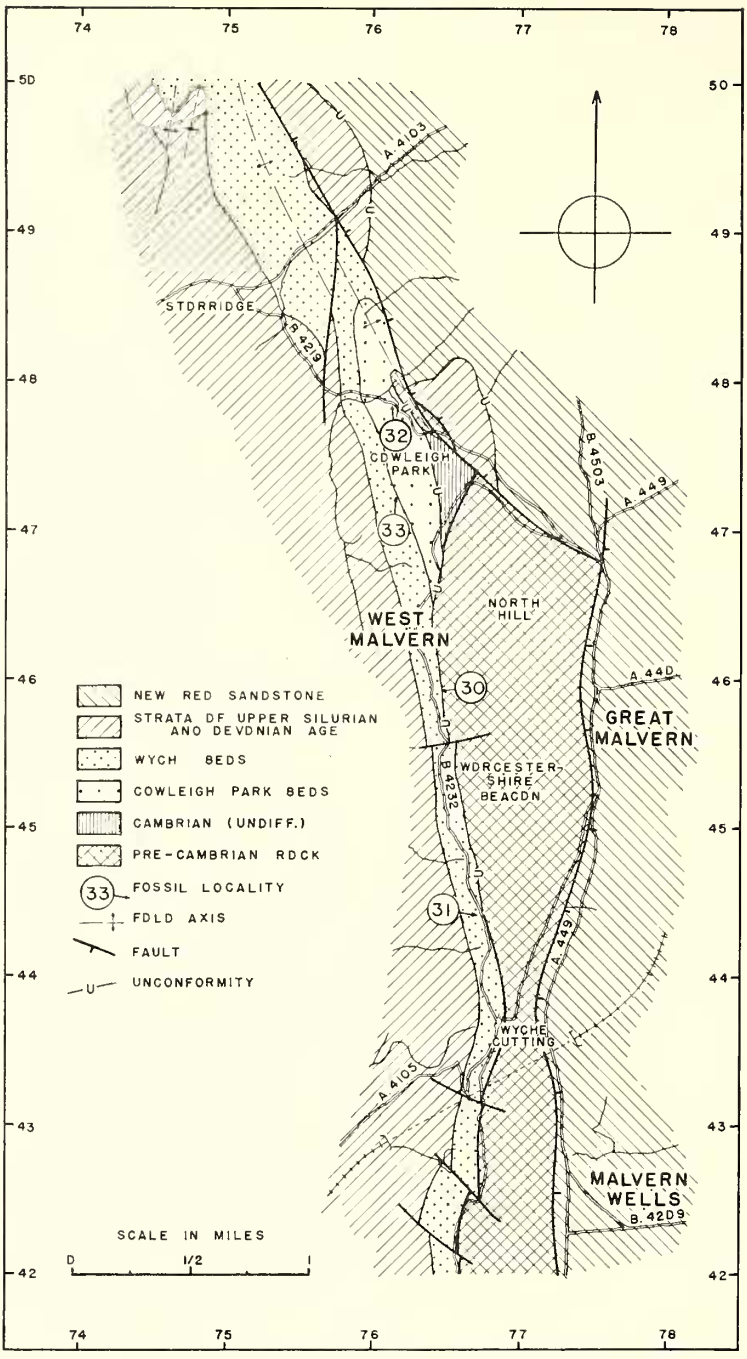
(*a*) *Cowleigh Park Beds*. Exposures of this formation are scattered, but our mapping suggests that there are at least four distinct members:

1. A basal member of up to 15 ft. (5 m.) of red micaceous mudstone interbedded with several thin (4 in. (10 cm.) or less) green sandstones composed of round quartz grains about 1 mm. in diameter. These were exposed during a Geologist's Association field trip in 1963, leader Mr. N. E. Butcher, with the aid of a mechanical digger, near the base of the Silurian to the south-west of Bronsil Castle.

2. About 100 ft. of light brown siltstones and sandstones containing fossils of the *Lingula* Community and occasional pebbles of Malvernian rock. This lithology crops out in both Cowleigh Park and in the Eastnor Obelisk—Howler's Heath area (Loc. 32, 23, and 24).

3. A coarse pink sandstone about 100 ft. (33 m.) thick which forms a ridge extending south-south-east from Rough Hill (SO/758 482) into Cowleigh Park. A similar topographic feature extends from Eastnor Obelisk to the eastern margin of Howler's Heath, and, though there are no outcrops there, loose blocks of a similar pink sandstone occur, containing chips of Cambrian shale.

4. Up to 200 ft. (65 m.) of unsorted purple conglomerates with angular pebbles up to 3 cm. in diameter, interbedded with coarse green sandstones up to a foot thick. This unusual lithology is known only from Cowleigh Park (SO/7616 4723) and may be restricted to this area which is immediately adjacent to the Malvernian ridge source area.



TEXT-FIG. 7. Locality map of the northern Malvern Hills, West Malvern, and Cowleigh Park areas. This map is continuous with text-figs. 6 and 8.

To the south-west of the Malverns, Holl (1865, fig. 4) and Groom (1899, p. 167) have described the unconformable relationship at the base of the Cowleigh Park Beds where the Llandovery rocks rest on the Tremadocian Bronsil Shales between the Obelisk and Howler's Heath. Although Cambrian shales have never been mapped to the north-west of the Malverns, it is probable that a similar unconformity exists in the Cowleigh Park area; Groom (1900, p. 157) states that Cambrian shale was exposed in a well 1 mile north of West Malvern, near the foot of North Hill. Our interpretation of the geology is given in text-fig. 7.

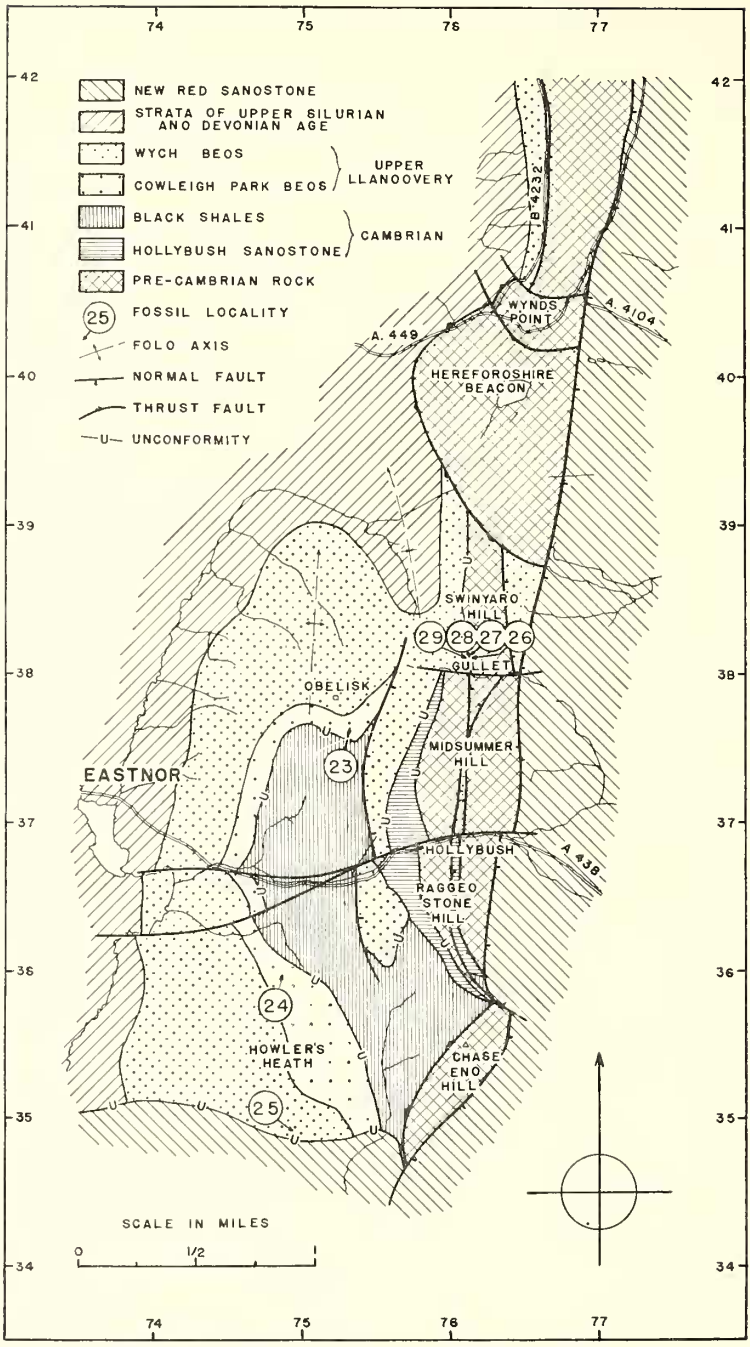
The pebbles in the conglomerates show that a landmass composed of Malvernian and Cambrian rocks was being eroded—this source area may have extended eastwards from the present-day Malvern Hills. The thickness of the Cowleigh Park Beds is perhaps 250 ft. (80 m.) at the Eastnor Obelisk. At Cowleigh Park there is probably between 350 and 400 ft. (100–30 m.), but lack of exposures and the possible presence of faults make this estimate uncertain.

Fossil communities. The *Lingula* Community is the only fossil community represented in the Cowleigh Park Beds of the Malverns; the fossils are confined to the second (siltstone and sandstone) member. They have been collected from Cowleigh Park (Loc. 32), south of the Obelisk (Loc. 23), and north of Howler's Heath (Loc. 24). This community indicates very shallow marine conditions, and it is possible that some of the Cowleigh Park Beds are beach deposits. The coarseness of the sediments and the absence of the *Eocoelia* Community indicate environments nearer to the shore-line than those in correlated beds to the north-north-west near Old Storridge Common and Ankerdine Hill, and to the south-south-west at May Hill.

Correlation. No fossils of value in correlation occur in the Cowleigh Park Beds of the Malverns. Comparison with Old Storridge Common to the north and with May Hill to the south suggests an early Upper Llandovery or late Middle Llandovery age.

(*b*) *Wych Beds.* The Wych Beds are seen resting on the fourth (conglomerate) member of the Cowleigh Park Beds at the Cowleigh Park football field (SO/7616 4723); the basal 6 ft. (2 m.) are coarse sandstones (they appear to be re-worked Cowleigh Park Beds) with occasional broken *Pentameroides*, which probably indicate a deeper-water environment than in the Cowleigh Park Beds; these sandstones are followed by shales and green siltstones typical of the main mass of the Wych Beds. The only other two exposures of the base of the Wych Beds are on the western margin of the Malvern Hills at West Malvern (SO/7646 4554) commonly known as the Sycamore tree quarry (Robertson 1926, p. 168), and the Gullet Quarry (SO/7612 3811) (Reading and Poole 1961); at both these places a basal conglomerate is present, up to 2 or 3 ft. (1 m.) thick. The conglomerate consists of rounded boulders of various Malvernian rocks, ranging from 4 mm. to 80 cm. in diameter, set in a matrix of green siltstone and mudstone—typical of the Wych Beds—containing a rich fauna of brachiopods and corals (see below).

The Wych Beds are poorly exposed and their thickness is determined with difficulty; estimates of about 400 ft. (130 m.) have been obtained from sections near Eastnor Obelisk and in Cowleigh Park. This is about the same thickness as at Old Storridge Common. It includes all the beds up to the base of the Woolhope Limestone, that is, where calcareous nodular beds become abundant.



TEXT-FIG. 8. Locality map of the southern Malvern Hills. This map is continuous with text-fig. 7.

Fossil communities. The fossils in the matrix of the conglomerates at West Malvern (Loc. 30) and the Gullet Quarry (Loc. 26) contain many species that are absent elsewhere in the Upper Llandovery of the Welsh Borderland, apart from Bog, Shropshire, and are interpreted (Ziegler, Cocks, and Bambach 1968), as a mixture of rocky bottom and soft bottom animals. Rocky bottom communities are usually in the areas of erosion, and do not frequently get preserved, but in this case the beds immediately above the conglomerate at the Gullet Quarry contain a *Pentameroides* Community (Loc. 27), and the fauna on the rounded boulders probably lived well below low-tide level and uncovered by sediment for a long period.

At Cowleigh Park (SO/7616 4723) the basal 6 ft. (2 m.) of the Wych Beds are coarse sandstones containing broken *Pentameroides*, and at the same exposure (Loc. 33) the *Costistricklandia* Community was found in typical Wych Beds lithology a few feet above the highest sandstone. Higher horizons in the Wych Beds also yield the *Costistricklandia* Community at Gullet Quarry (Locs. 28, 29) and on the south side of Howler's Heath (Loc. 25). The *Clorinda* Community has been found at West Malvern (Loc. 31) indicating, as at Old Storridge Common, still deeper water in the upper part of the Wych Beds.

Correlation. At Gullet Quarry *Eocoelia curtisi* is present in the basal Wych Beds (Locs. 26, 27). This species is of C_5 age, as is *Costistricklandia lirata alpha* which occurs in higher beds at Gullet Quarry (Locs. 28, 29). The Cowleigh Park (Loc. 33), and West Malvern (Loc. 31) collections contain *C. lirata typica*, showing that, in the Malverns, the greater part of the Wych Beds is of C_6 age.

WOOLHOPE

Text-fig. 3, col. 26

Squirrel and Tucker (1960) proposed the names Lower Haugh Wood Beds and Upper Haugh Wood Beds for the Llandovery rocks exposed in the Woolhope dome, east-south-east of Hereford. The former are at least 280 ft. (90 m.) thick, their base unexposed, and are lithologically similar to the Wych Beds of the Malverns. The Upper Haugh Wood Beds are 30 ft. (10 m.) thick; the basal 20 ft. (7 m.) are purple and green muddy siltstones, but more calcareous beds are present in the top 10 ft. (3 m.).

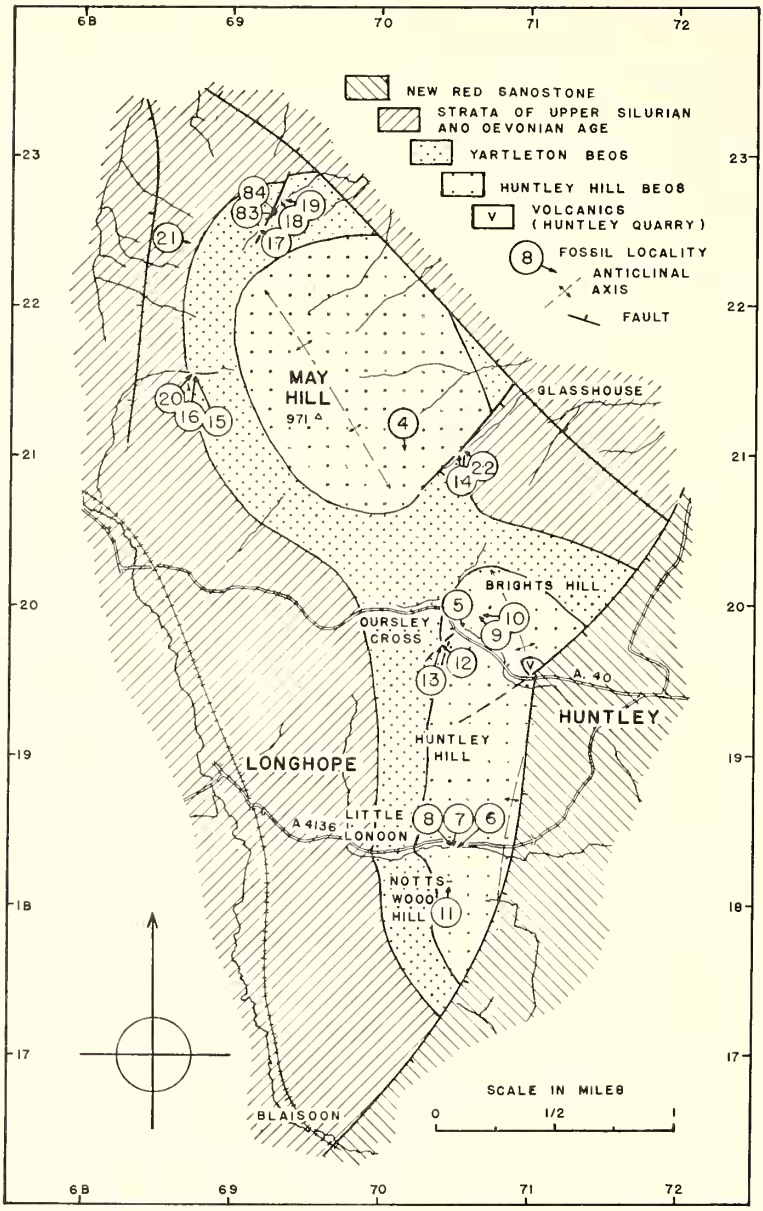
Fossil communities. In the Lower Haugh Wood Beds the *Costistricklandia* Community is represented by collections from Kidley Coppice (Loc. 85) and Rudge Wood (Loc. 86). Judging from the faunal lists of Squirrel and Tucker this community is also present in the Upper Haugh Wood Beds.

Correlation. C. lirata typica occurs in both the Lower and Upper Haugh Wood Beds, indicating a C_6 age. The *Petalocrinus* Limestone is present in the highest 10 ft. (3 m.) of the Upper Haugh Wood Beds; it was found by Pocock (1930, pp. 60–1) at equivalent horizons in the May Hill and Malvern areas, but these exposures are now obscure. It is very close to the lithological boundary at the base of the Woolhope Limestone, and we conclude that this limestone is of late C_6 or early Wenlock age.

MAY HILL

Text-fig. 3, col. 27

Llandovery Beds are exposed in the core of an anticlinal structure at May Hill, 8 miles west of Gloucester (text-fig. 9). Two formation names, Huntley Hill Beds and



TEXT-FIG. 9. Locality map of the May Hill Inlier (after Lawson 1955, with minor changes).

Yartleton Beds, were proposed by Gardiner (1920) who also proposed the term Huntley Quarry Beds for 'Fine and somewhat coarse grits, containing lapilli' for beds in the vicinity of the quarry. At the present time, volcanic flows with interbedded red-beds are seen in Huntley Quarry, and these apparently underlie coarse sandstones with angular fragments of the volcanic rocks which grade up into fossiliferous Llandovery sediments.

The contact is obscure and faulted but it is probable that the Llandovery lies unconformably on these volcanics, which might possibly be correlated with similar volcanics in the Malvern Hills assigned to the Pre-Cambrian Warren House Series (Groom 1910). We regard the coarse grits in the vicinity, which have sometimes been included in the Huntley Quarry Beds, as the basal part of the Huntley Hill Beds, and propose the term Huntley Quarry Volcanics for the volcanic rocks and their associated red beds.

We also differ from the current literature concerning the relationship of the Yartleton Beds and the Woolhope Limestone. It has long been known (Phillips 1848, pp. 184–5) that a series of sandstones occur within the Woolhope Limestone sequence at Little London (SO/700 184) in the southern part of the inlier. Our mapping shows that the sandstone at Old Oaks Farm Quarry (Loc. 21) and the stream section near Hill Farm (Loc. 22) in the north-west and central parts of the inlier are also within the Woolhope sequence; in these two areas Lawson (1955) mistakenly referred these Woolhope sandstones to the Llandovery. Except for these minor points, we agree with Lawson's map of the Llandovery beds.

(*a*) *Huntley Hill Beds.* Lawson's (1955) minimum thickness of 600 ft. (200 m.) is probably an underestimate. The Little London stream section (SO/7085 1832 to SO/6997 1834) where the beds, with the exception of one outcrop, dip continuously to the west, suggests a thickness of about 850 ft. (280 m.). The oldest beds exposed in this section are on strike with the basal beds at Huntley Quarry, and are therefore near the base of the formation.

The Huntley Hill Beds are mostly grey coarse sandstones and conglomerates; they weather to a buff colour and are often reddened in areas close to the Triassic cover. The sandstone beds are normally one to 2 ft. thick; they show lateral changes in thickness, and they have little internal structure except towards the top of the formation where thinner bedded sandstones are present with fine parallel laminations. Shales are rare, but a few tens of feet of shale are exposed in the Little London stream (SO/7057 1837) at about 300 ft. above the base of the formation.

The pebbles in the conglomerates include the distinctive quartz-orthoclase plutonic rocks of the Malvern Hills. Volcanic pebbles are also present and could have been derived from other Malvern rocks or, in the case of the angular andesite prophyry pebbles, directly from the Huntley Quarry Volcanics. There is no doubt that adjacent pre-Cambrian rocks were being eroded at this time.

Fossil communities. The lowest 350 ft. (115 m.) of the Huntley Hill Beds are largely barren of fossils, but *Lingula pseudoparallela* has been reported from the basal sediments of Huntley Quarry (Symonds 1872, pp. 147–8). *Eocoelia hemisphaerica* and other representatives of the *Eocoelia* Community have been collected in the Little London stream section at about 350 ft. (Loc. 6) and 410 ft. (Loc. 7) above the supposed base of the formation; closely similar assemblages also occur near Dursley Cross (Loc. 5) and on the south-east side of May Hill (Loc. 4). At higher stratigraphical levels there is a reversion to the *Lingula* Community; about 440 ft. (140 m.) above the base in the Little London stream (Loc. 8), and in old quarries on Brights Hill (Locs. 9, 10). The highest Huntley Hill Beds are poorly exposed; a single fossil locality near old quarries at the top of Nottswood Hill (Loc. 11) has yielded the *Eocoelia* Community, with *E. intermedia* at about 610 ft. above the base of the formation.

Correlation. The lowest, largely unfossiliferous 350 ft. (115 m.) may be pre-Upper Llandovery in age. The beds between 350 and 410 ft. (115–35 m.) from the base of the formation in the Little London stream section are known to be of C_1 or C_2 age from the presence of *E. hemisphaerica*, as are the beds that have been correlated with these at Dursley Cross and May Hill. The Nottswood Hill quarries at around 610 ft. (200 m.) from the base contain *E. intermedia* of C_3 or C_4 age.

(*b*) *Yartleton Beds*. The lower contact of the Yartleton Beds is not exposed, but there appears to be a gradational transition from the coarse sandstones of the Huntley Hill Beds to the fine laminated sandstones (typically 3–4 in. thick), siltstones and shales of the Yartleton Beds. The formation is about 500 ft. (160 m.) thick.

Fossil communities. Fossil localities are abundant in the Yartleton Beds, but there are no well-exposed sections showing the stratigraphic relationships between exposures more than a few feet apart, as most of the outcrops occur along streams in the vicinity of faults. The fossil collections however can be arranged stratigraphically by comparing the *Eocoelia*, stricklandiids and pentamerinids with contemporaneous sections at Llandovery and in other parts of the Welsh Borderland. Table 1 summarizes the data for eleven localities at May Hill. The method used for calculating percentages is described in Ziegler, Cocks, and Bambach (1968, p. 4).

Except for the two collections (Locs. 18, 19) within 100 ft. (33 m.) of the Woolhope Limestone, all the Yartleton fossils belong either to the *Pentameroides* or *Costistricklandia* Communities or to mixtures of the two. Some changes in community composition apparently took place in a short period of time, for example, Locality 16, with 34% *Pentameroides* and 44% *Costistricklandia* contains elements of both communities but occurs a few inches above Locality 15 which consists of *Costistricklandia* with 8% *Clorinda*. Locality 16 may have a fauna from the boundary between the *Costistricklandia* and *Pentameroides* Communities, or it may be due to mixing of faunas after death. Locality 18 is interpreted as a death assemblage; it contains fairly abundant *Eocoelia* together with some deeper-water species. The highest locality in the Yartleton Beds, 19, is assigned to the *Clorinda* Community and represents deeper water than the earlier faunas.

Correlation. The majority of the Yartleton Beds are of C_5 and C_6 age (Table 1). It is possible that the basal parts are C_4; Locality 12 has no *Eocoelia* nor pentamerinids, and the stricklandiids are fragmentary and cannot definitely be assigned to *Stricklandia* or *Costistricklandia*, so it could represent an earlier horizon than the remaining collections.

At May Hill there is a transition between the Llandovery and Wenlock Beds. Phillips (1848, pp. 74–5, 184–5) arbitrarily drew the contact at the first appearance of limestone. Unfortunately the Woolhope Limestone and the overlying Wenlock Shales in the southern part of the Welsh Borderland have not yet yielded any graptolites that allow correlation with the graptolite zones and Phillips' arbitrary criterion must continue for the time being.

TORTWORTH

Text-fig. 3, cols. 28 and 29

Curtis (1955) has assigned the Llandovery rocks of this area (text-fig. 10) to two formations: the Damery Beds and the Tortworth Beds. These are separated by the 'Upper

Trap', an andesite flow with a fossiliferous ashy tuff bed on its upper surface (Reed and Reynolds 1908, p. 515, Reynolds 1924). The basaltic 'Lower Trap', considered intrusive by Reynolds (1924) but extrusive by Curtis, occurs at the base of the Damery Beds, resting unconformably on Tremadocian shales. Both basalts thin towards the north-west, and appear to be absent north of Stone.

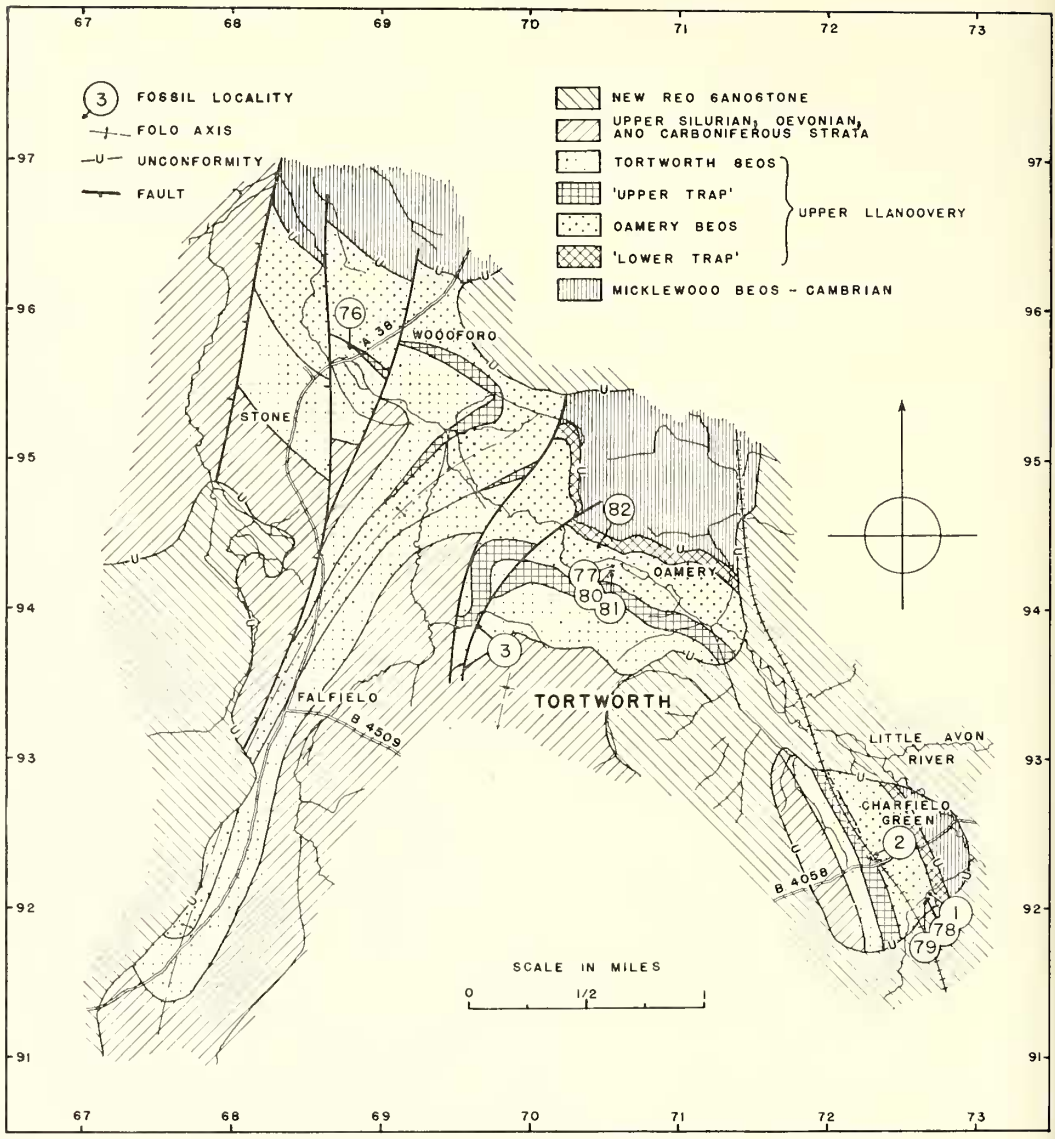
(*a*) *Damery Beds.* This unit is comprised of about 500 ft. (160 m.) of alternating fine-grained sandstone and shale beds (Curtis, 1955), with the former being dominant in the lower part of the unit.

TABLE 1. Critical community and dating elements of the collections from the Yartleton Beds (E, *Eocoelia*; P, *Pentameroides*; S, *Costistricklandia*; and C, *Clorinda*)

Section	*Loc.*	*Community elements* E	P	S	C	*Community*	*Dating elements*	*Date*	*Stratigraphical notes*
Stream 450 yd. W. of Hay Farm (NE. side of May Hill)	19	7%	0%	3%	10%	C	*E. sulcata* *C. lirata typica*	C_6	Within 100 ft. of Woolhope Lst.
	18	18	0	1	1	..	*E. sulcata* *C. lirata typica*	C_6	Along strike from Loc. 19.
	84	3	0	8	1	S	*E. sulcata* *C. lirata typica*	C_6	10 ft. above Loc. 83.
	83	12	18	26	0	P/S	*E. sulcata* *Pentameroides* sp. *C. lirata typica*	C_6	(See above.)
	17	0	0	42	0	S	*C. lirata alpha*	C_5	
Stream S. of Pitman's Farm (W. side of May Hill)	20	4	0	4	0	S	*E. sulcata* ? *C. lirata typica*	C_6	
	16	0	34	44	0	P/S	*Pentameroides* sp. *C. lirata alpha*	C_5	A few inches above Loc. 15.
	15	0	0	29	8	S	*C. lirata alpha*	C_5	(See above.)
Stream NW. of Hill Farm (SE. side of May Hill)	14	3	37	7	0	P	*E. curtisi* ? *Pentameroides* sp.	C_5	
Stream S. of Hollybush Farm, Dursley Cross	13	3	34	19	0	P	*E. curtisi* ? *Pentameroides* sp.	C_5	
	12	0	0	34	0	S		?C_5	

Fossil Communities. The *Eocoelia* Community is present in the basal 130 ft. (43 m.) of the Damery Beds. Collections have been made within a few feet of the top of the Lower Trap in Damery Quarry (Loc. 82), and in higher beds at Charfield Green (Loc. 1) and near Damery Bridge (Loc. 77). The *Pentameroides* Community has been recognized in two collections, 10 ft. (3 m.) stratigraphically apart in the middle of the formation at Charfield Green (Locs. 78, 79). Still deeper water is indicated by the presence of the *Costistricklandia* Community in the top two-thirds of the Damery Beds; collections have been made on the road south of Damery Bridge at about 165 and 176 ft. (54–7 m.) above the base of the formation (Locs. 80, 81), and in the railway cutting at Charfield Green (Loc. 2) within 25 ft. (8 m.) of the top of the formation.

Correlation. Eocoelia curtisi occurs in all the collections from the lowest third of the Damery Beds, and *Costistricklandia lirata alpha* is present in the collections from the upper two-thirds of the formation. These show that all the Damery Beds are of C_5 age. The stream south of Charfield Green (Loc. 2) is the type locality of *E. curtisi* (Ziegler 1966*b*, p. 537).



TEXT-FIG. 10. Locality map of the Tortworth Inlier (after Curtis 1955).

(*b*) *Tortworth Beds.* The lithology of these beds is similar to the shales and fine-grained sandstones of the Damery Beds. Exposures are rare except near the base; Curtis (1955) estimates the thickness at 200 ft. (65 m.), but the upper contact appears to be gradational with an impersistent limestone forming the base of the Wenlock in the western parts of the Tortworth inlier.

Fossil communities. The only collections from the Tortworth Beds are from near the base. In Daniel's Wood (Loc. 3), the *Eocoelia* Community is present within a few feet

of the Upper Trap which is 150 ft. (50 m.) thick here; but north-east of Stone (Loc. 76) the *Costistricklandia* Community occurs in the basal foot of the Tortworth Beds where the basalt is only about 15 ft. (5 m.) thick. The different thicknesses of the lava appear to have controlled the local depth of water; *Costistricklandia* Community depths are present before and after the flow where it is thin, but where the flow is 150 ft. (50 m.) thick the deeper-water *Costistricklandia* Community at the top of the Damery Beds is replaced by the shallower-water *Eocoelia* Community above the andesite (Ziegler 1965).

Correlation. Eocoelia sulcata is present in both collections from the base of the Tortworth Beds; *Costistricklandia lirata alpha* is also present north-east of Stone (Loc. 76). The presence of *C. lirata alpha* and *E. sulcata* indicates that the horizon must be near the C_5–C_6 boundary.

WALSALL AND GREAT BARR

Text-fig. 3, col. 6

Butler (1937) has described Llandovery rocks in the Walsall Borehole, and Jukes (1853) and Eastwood *et al.* (1925, p. 11), mention a very small area of the Llandovery rocks at Great Barr near the Eastern Boundary Fault of the South Staffordshire Coalfield. The Walsall Borehole penetrated Wenlock Limestone, Wenlock Shale, Barr Limestone, and below this, some 457½ ft. (150 m.) of shales, mudstones, siltstones, and sandstones before hitting Cambrian quartzite with a dip differing by 8° to 15° from the Silurian. Some of the beds beneath the Barr Limestone are Wenlock in age as *Cyrtograptus murchisoni* has been recorded 36 ft. (12 m.) below this unit (depth 831½ ft.), but 74½ ft. (24 m.) below the Barr Limestone (depth 870 ft.) are purple and green shales, similar to the Hughley Shales of Shropshire, and we prefer to draw the Wenlock-Llandovery boundary at this point. Butler records 24 bentonitic clays above depth 870 ft., and 27 bentonites below this depth; one bed is 7 in. (18 cm.) thick, the remainder range from 2 in. down to $\frac{1}{16}$ in. (5 cm.–1·5 mm.).

Fossil communities. The beds from 28 to 303 ft. (9·5–100 m.) above the base of the Silurian (depths 1225 to 950 ft.) contain *Costistricklandia*; in this sequence, *Pentameroides* (previously recorded as *Pentamerus oblongus*) is known only over a short thickness (233–48 ft. (76–81 m.) above base, or depths 1020 to 1005 ft.), so it appears probable that the Llandovery beds accumulated mainly in the moderate depths characteristic of the *Costistricklandia* Community. This interpretation agrees well with Butler's (1937, p. 251) picture of the depositional environment. The *Costistricklandia* Community also occurs at Great Barr where a Llandovery quartzite is exposed south-south-east of the house formerly known as the Australian Arms (SP/038957).

Correlation. Costistricklandia lirata alpha occurs between 28 and 93 ft. (9·5–31 m.) above the base of the sequence (depths 1225 to 1160 ft.) (Butler, 1937, p. 247), showing that the oldest Llandovery in this area is of C_5 age. *C. lirata typica* has been recorded between 123 and 283 ft. (41–93 m.) above the base (depths 1130 to 970 ft.), which proves a C_6 age for these beds. Graptolites occur at several horizons; those that Miss Elles examined from below 120 ft. (39 m.) from the base (depth 1133 ft.) are 'suggestive of the Upper Valentian', and those below 27 ft. (9 m.) from the base (depth 1226 ft.) suggest a horizon at least as low as the *M. griestoniensis* Zone (Butler 1937, p. 246). At the Great Barr exposure, we have collected *C. lirata typica.*

RUBERY

Text-fig. 3, col. 8

Llandovery rocks rest with slight angular unconformity on the Lickey Quartzite (Cambrian) to the north and south-east of Rubery (Wills *et al.* 1925, 1938, Eastwood *et al.* 1925, p. 12); the latter authors infer that it occurs in hollows in the quartzite. Wills *et al.* (1925, p. 68 and 1938, p. 177) describes the Rubery Shales Series as consisting of a minimum of 40–50 ft. (13–16 m.) of shales and thin sandstones with some calcareous beds; these rest on 100 ft. (33 m.) of Rubery Sandstone Series which are coarse and fine sandstones, some shale and a basal conglomerate.

Fossil communities. Costistricklandia is present in both the Rubery Sandstone series and the Rubery Shale Series; the faunal list of Wills *et al.* (1925, pp. 72–3) suggests that the *Costistricklandia* Community is present throughout the whole Llandovery sequence in this area, although *Pentameroides* does occur in some beds.

Correlation. Costistricklandia lirata alpha is abundant in the Rubery Sandstone Series (St. Joseph 1935, p. 419) and *Pentameroides* also occurs (previously recorded as *Pentamerus oblongus*). The higher Rubery Shale Series contains *C. lirata alpha*, *Monograptus marri* and *M. nudus*. It is concluded that the section described by Wills *et al.* (1925, p. 68) is all of C_5 age.

The fossils listed (Eastwood *et al.* 1925, pp. 14–15) as coming from Wenlock beds near Rubery Hill Asylum (SO/992778) include undoubted Llandovery fossils, but we have not examined this locality.

COVENTRY

Text-fig. 3, col. 9

Shotton (1927) records Upper Llandovery sandstone pebbles from the Corley Conglomerate of Upper Carboniferous age, which is exposed from Coventry to Corley and Hollyberry End (SP/262842) 6 miles to the north-west. Shotton has shown that, approaching Coventry from the north-west, the proportion of Llandovery sandstone pebbles increases from 46% at Hollyberry End, to 70% at Corley (SP/304850) and 85% at King Street, Coventry (SP/333797). This traverse along the present outcrop of the Corley Conglomerate runs obliquely to a south-south-eastward extension of the Nuneaton Ridge (composed of Cambrian and Precambrian rocks), and Shotton suggests (1927, p. 616) that this ridge was capped by a strip of Upper Llandovery rocks (as at Walsall and Rubery) which provided the pebbles. It is probable that the source area extended north-north-west from around Binley, 3 miles east of Coventry.

Fossil communities. The faunal list (Shotton 1927, pp. 609–10) contains 55 species, which, with one or two possible exceptions, are typical of, or known in, the *Eocoelia* Community. Stricklandiids, which are dominant to the west at Rubery and Walsall, are absent, as are *Pentameroides* and other elements of the offshore communities.

Correlation. Examination of *Eocoelia* in pebbles (some kindly lent from the Birmingham University collections by Professor Shotton, others in the Sedgwick Museum, Cambridge) show the present of *E. intermedia*, *E. curtisi*, and *E. sulcata*, which indicates

ages from C_{3-4} through C_5 to C_6. This is the only record of Silurian beds as old as C_{3-4} to the east of the Malvern line.

LOWER LEMINGTON

Text-fig. 3, col. 20

Silurian rocks are recorded below Coal Measures in Strahan's (1913) description of a borehole 350 yd. W. 22° N. of Lower Lemington Church, 1 mile north-east of Moreton-in-Marsh. Grey shales with sandstone and limestone occurred from a depth of 1546 ft. (510 m.) to the completion of the hole at 1700 ft. (558 m.); allowing for a dip of 22°, the strata proved are about 140 ft. (46 m.) thick.

Fossil communities. Examination of the fossils in the Geological Survey collections (JP3143–61) from between 1590 and 1682 ft. show an *Eocoelia* Community present throughout this thickness.

Correlation. The *Eocoelia* present are all *E. sulcata*, indicating a C_6 age for all the fossiliferous Silurian beds that were penetrated.

EASTERN MENDIPS

Curtis (1955) summarizes the earlier work of Reynolds (1907, 1912, 1929) on the stratigraphy of the Silurian inlier which extends $3\frac{1}{2}$ miles westwards from Downhead, Somerset:

3. Wenlock mudstones with some micaceous sandstones (120 ft.—40 m.).
2. Andesites and tuffs (at least 400 ft.—130 m.).
1. Tuffs (110 ft. (36 m.) seen). These oldest beds have, in the past been assigned to the Upper Llandovery.

Fossil communities. A collection from a field 1 mile west of Downhead (Loc. 94) yielded a dominance of *Salopina* and *Sphaerirhynchia*, which suggest a near-shore environment for beds which our interpretation of the literature suggests are beneath the andesites.

Correlation. It is probable that there are no Llandovery beds exposed in the inlier. Collections from tuffs (ST6752 4584) suggest an environment similar to the *Eocoelia* Community of the Llandovery, but no *Eocoelia* or other distinctive Llandovery forms have been found by us or recorded in the literature. We have examined the specimens (GSM DEW 3833–935) upon which Green (1962) based his report of beds attributable to the Llandovery, and conclude that they are also of Wenlock or Ludlow age. We thus tentatively consider these beds to be of Wenlock age. This conclusion is supported by the presence of *Acaste downingiae* (Reynolds 1907, p. 227, Curtis 1955, p. 7) which we believe to be absent in the Llandovery.

RUMNEY

The Silurian inlier at Rumney (Rhymney), $2\frac{1}{2}$ miles north-east of the centre of Cardiff, has been described by Sollas (1879). The Silurian beds in this inlier have always been assigned to the Wenlock and Ludlow, although Sollas recorded *Pentamerus* and *Stricklandia*.

The problem has been investigated by Dr. M. G. Bassett, who kindly writes: 'I am certain that all the beds are Wenlock–Ludlow. The best exposure at present is at

Penylan Quarry, where virtually the oldest beds brought to the surface in the inlier are exposed. These beds are certainly below the Rumney Grit, and hence older than the horizons from which Sollas quoted his diagnostic Llandovery brachiopods. The beds at Penylan contain abundant *Meristina obtusa*, which I consider to be a good indicator of late Wenlock age. This is supported by the occurrence of other fossils which could only be Wenlock or Ludlow in age.' In addition there are many Wenlock brachiopods from the inlier at the National Museum of Wales which bear old labels mis-identifying them as '*P. oblongus*' and '*Stricklandia*'.

BREIDDEN HILLS

Text-fig. 3, col. 4

Watts (1885, pp. 536–7) gave the first description of the Llandovery beds of the Breiddens, and Wade (1911, p. 419) subdivided these beds into a lower unit, the Cefn Beds, and an upper unit, the Buttington Shales. The use of local names is preferable to the Shropshire names employed by Whittard (1932, pp. 880–2) in his description of this area. These beds are exposed sporadically along a 5-mile strip of country north-east of Buttington Station; the largest exposures are in the Brick Works (SJ/265 100) a quarter of a mile east of the station, and adjacent road sections.

(*a*) *Cefn Beds.* Whittard (1932) states that these consist of about 300 ft. (100 m.) of sandy mudstones with calcareous sandstones and occasional conglomeratic beds, but in the south-west the calcareous beds are more common. Ripples exposed at the top of the formation, over a large face in Buttington Brick Works, give a direction of movement from east to west.

Fossil communities. Whittard (1932, p. 881) mentions two fossil localities: north of Middletown in the centre of the outcrop (SJ/3008 1276) within 50 ft. (16 m.) of the base, and at the south-west end, south-east of Buttington Station (SJ/2633 0997) within 100 ft. (33 m.) of the base of the formation. Our collections show that the *Stricklandia* Community is present in both places.

Correlation. The presence of *Stricklandia lens* cf. *intermedia* suggests a Middle Llandovery age for the lower part of this formation.

(*b*) *Buttington Shales.* Whittard (1932, p. 881) described maroon, green, and blue mudstones with some calcareous beds up to 6 in. (15 cm.) thick, becoming uniformly maroon towards the top; he estimated their thickness to be about 350 ft. (115 m.). The upper contact is defined by an abrupt termination of the maroon coloured beds; above this Cocks and Rickards (in press) record the presence of a complete succession of Lower Wenlock graptolite zones at Buttington Brick Works.

Fossil communities. The Buttington Shales have few fossils, but we have a collection, from near the top of the sequence in the Brick Works, in the *Clorinda* Community. Whittard (1932, p. 882) also found fossils in loose blocks at the north-east end of the outcrop; his faunal list is also typical of the *Clorinda* Community.

Correlation. It is not possible to state what horizon within the Llandovery is represented by these two collections from the Buttington Shales, but they are overlain with apparent conformity by a basal Wenlock *centrifugus* Zone fauna.

WELSHPOOL

Text-fig. 3, col. 3

Wade (1911) described two formations of Llandovery age in the Welshpool area, the Powis Castle Beds and the higher Cloddiau Beds. The poorly exposed outcrop extends from Belan (2 miles south-west of Welshpool) to the Llansantffraid ym Mechain area, north-east of Meifod (see below).

(*a*) *Powis Castle Beds.* This unit consists of 100 ft. (33 m.) of massive bedded conglomerates; sandstones, shales and limestones are also present (Wade 1911, p. 431). It rests on Ashgill beds (*Phillipsinella parabola* age) in the Gwern y Brain (SJ/219 128) (Cave 1965, p. 282) and at the Laundry (SJ/197 103) (ibid., p. 295). Towards Welshpool the uppermost Ordovician beds are overstepped and the Powis Castle Beds rest on Lower Caradoc rocks (Harnagian Stage). In the Gwern y Brain, the Powis Castle Beds contain angular pebbles of these Ashgill and Caradoc units.

Fossil communities. A collection from the Gwern y Brain (SJ/2186 1283) within 10 or 15 ft. (3–5 m.) of the base of the Powis Castle Beds has yielded nothing but derived fossils from the underlying units, but the angularity of the pebbles and boulders is very suggestive of deposition in non-marine conditions. We have found the *Cryptothyrella* Community, a probable early Llandovery equivalent of the *Eocoelia* Community, in a loose block in the southern part of the area, 600 yd. west of Belan Locks (SJ/2100 0518). On Cherry Tree Bank (SJ/2226 0831) on the north edge of Welshpool, we have collected *Clorinda* from the higher beds of the unit, and this would suggest that some of the Powis Castle Beds accumulated in deeper water; this conclusion is strengthened by the presence of *Stricklandia lens* in the conglomerates in the north of Powis Castle Park. In fact, the full depth range of communities may be present in the formation.

Correlation. The fact that the overlying Cloddiau Beds contain a Lower Llandovery graptolite fauna (*vesiculosus* Zone) suggests that the Powis Castle Beds are of Lower Llandovery age, and suggests a short pause in sedimentation between the Ashgill beds in the Gwern y Brain and the earliest Silurian. The presence of *Stricklandia lens* indicates a Llandovery as opposed to a late Ordovician age for the unit.

(*b*) *Cloddiau Beds.* Around Welshpool, upper Silurian beds rest directly on the Powis Castle Beds, but from Cloddiau northwards, some 250 ft. (80 m.) of mudstones and siltstones are seen above the conglomerates.

Fossil communities. A collection from the Cloddiau Beds at Y Frochas (SJ/1955 0824) yielded the *Clorinda* Community.

Correlation. Wade (1911, p. 434) reported *Climacograptus innotatus*, *C. cf. rectangularis* and *C. medius* from the lower part of the formation near Cloddiau. These indicate the *vesiculosus* Zone, but as they were found only 20 ft. (7 m.) above the base of the formation, it is possible that the Middle and Upper Llandovery is also present—the Cloddiau Beds extent upwards into Wenlock strata with no change in dip.

MEIFOD

Text-fig. 3, col. 2

The Llandovery outcrop extends northwards from Welshpool for 7 miles to the Llansantffraid ym Mechain area (Whittington, 1938), and thence changes direction south-westwards to Meifod (King, 1928). King recognized four formations which he labelled V_1, V_2, V_3, and VS and Whittington employed this terminology at Llansantffraid ym Mechain.

(*a*) *Craig-wen Sandstone* (*V_1*). This basal unit is a 30-ft. (10 m.) sandstone with some large calcareous concretions near the base. The sandstone fills hollows cut in Ashgill mudstone south-west and west of Meifod at Graig-wen and Glan-yr-afon-isaf (King 1928, pp. 682–3). These hollows are a foot or more in depth and contain angular fragments of Ashgill mudstone.

Fossil communities. King (1928, pp. 686–7, 699) records two communities from the Graig-wen Sandstone. In the calcareous beds fragmentary corals and brachiopods are present, while the sandstone contains 70% orthids, 20% *Cryptothyrella* (the *Meristina crassa* of earlier reports), and about 10% rhynchonelloids. Our collection from the basal $1\frac{1}{2}$ ft. (50 cm.) of the unit at Graig-wen Quarry (SJ/0991 0919) has yielded the *Cryptothyrella* Community, the probable early Llandovery equivalent of the *Eocoelia* Community.

Correlation. The fossils of this unit are not diagnostic as to age, but the underlying Ashgill unit has yielded graptolites normally associated with the *Dicellograptus anceps* zone (King, 1928, p. 698) and the overlying formation has yielded late Lower Llandovery graptolites, so the Graig-wen Sandstone is probably of early Lower Llandovery age.

(*b*) *Blue silty mudstones* (*V_2*). Blue-black micaceous shales and hard siltstones (V_{2a}) come at the base of this formation west of Meifod; higher beds (V_{2b} and V_{2c}) in this 630–ft. (205 m.) formation are blue mudstones with silty siliceous bands and calcareous nodules (King 1928, pp. 687–8). Five miles north-east of Meifod, Whittington (1938, pp. 438–42) describes blue mudstones and limestones near Tre-wylan House and Gelli Farm (which he correlates with King's V_{2b} beds) resting on Ashgill. Similar beds occur at Godor and it would seem likely that the outcrop is continuous with that of Meifod. Beds like King's V_{2c} are recorded at Godor and Sarnau (Whittington 1938, pp. 440–1).

Fossil communities. King (1928, p. 699) lists *Stricklandia* and *Clorinda* [*Barrandella*] as common in V_{2b}; and *Clorinda* as common in V_{2c}. This suggests deeper water than in the Graig-wen Sandstone.

Correlation. In the lower part of this unit, *Climacograptus normalis*, 'and what Dr. G. L. Elles thinks may be a specimen of *Monograptus acinaces*' have been found (King 1928, p. 688). These species would suggest the zone of *M. cyphus* (late Lower Llandovery), but the unit may extend into the Upper Llandovery as the lowest graptolite fauna in the overlying formation is in the *turriculatus* Zone.

(*c*) *Pale grey and purple-red shales* (*V_3*). King's (1928, p. 690) V_3 beds start with an abrupt change of colour from grey-blue mudstones to pale dove-grey fine mudstones; they consist of 330 ft. (110 m.) of pale grey and red shales.

Fossil communities. Apart from some fragmentary trilobites and brachiopods near the base, graptolites are the only fossils present.

Correlation. The zones present range from *turriculatus* to *crenulata* (King 1928, p. 690) and represent the upper two-thirds of the Upper Llandovery. The red shales occur in the *crispus* and *griestoniensis* Zones; they are the oldest dated red beds known in the Welsh Llandovery succession.

(*d*) *Passage Beds* (*VS*). King (1928, p. 691) records 60 ft. (20 m.) of blue-grey mudstones above V_3 beds.

Fossil communities. Benthic forms are absent from this unit.

Correlation. King found *Monoclimacis crenulata* in these beds to the north-east of Meifod, so they are assigned to the topmost Upper Llandovery. They are followed by lowest Wenlock beds with a similar lithology.

TRANNON AND LLANIDLOES

Text-fig. 3, cols. 1 and 10

These areas are in the middle of the graptolitic-greywacke facies of central Wales and have been included here because they contrast with the dominantly shelly facies of the Welsh Borderland areas already described. Wood (1906) and Jones (1945) have described the stratigraphy of the areas. At Trannon (called Tarannon by Wood) at least 3650 ft. (1200 m.) of Llandovery sediments (we use Llandovery to include all the beds up to the base of Wood's *murchisoni* Zone) are present, and 9670 ft. (3175 m.) at Llanidloes. In both areas the whole succession consists of graptolitic shales with greywackes at some horizons. The base of the Silurian is not quite reached near Trannon, but at Llanidloes a sharp but comfortable base is present.

Greywackes are especially abundant in the *griestoniensis* Zone. Bassett (1963, pp. 57–9) interprets the Talerddig Grits of Trannon and the contemporary Moelfre Group of Llanidloes as turbidites and comments on the problems in estimating the depth of water in which they were deposited. We would consider that these turbidites could have been laid down over a very large depth range, provided that the depth was greater than that of the *Clorinda* Community, which is completely absent around Trannon.

The highest Llandovery consists of purple and green mudstones which contain a fauna characteristic of the *crenulata* Zone. There is a gradational passage upwards into the Wenlock beds.

BUILTH WELLS

Text-fig. 3, col. 23

Upper Llandovery rocks occur in a very narrow discontinuous belt running north-east from Park Wells (SO/027 519—1 mile west-north-west of Builth Wells) for a distance of 4 miles (Jones 1947). The beds consist of about 50 ft. (16 m.) of coarse sandstone and mudstones, resting unconformably on Ordovician beds, and overlain unconformably by beds of Lower Wenlock age. The Wenlock overstep is considered to be responsible for the discontinuous outcrops (Jones 1947, p. 35).

Fossil communities. A collection from Trecoed (SO/0527 5516) has yielded an abundance

of *Pentamerus* and *Stricklandia*, suggesting a mixture of these two communities. These came from a coarse sandstone about 14 ft. (5 m.) above the base of the Llandovery.

Correlation. S. lens ultima is present, indicating a C_{3-4} age for this horizon.

GARTH

Text-fig. 3, cols. 21 and 22

The Garth area is situated some 15 miles north-east of Llandovery and is part of the same belt, which, during Llandovery times, formed the junction of the stable shelf to the south and east and the subsiding basin to the north and west. The two columns representing this area were selected to illustrate some of the many lateral changes in thickness and lithology in the Llandovery rocks of the Garth area. Andrew (1925) divided the Lower Llandovery into three formations, A_a, A_b, and A_c; designated the Middle Llandovery B; and divided the Upper Llandovery into C_a, C_b, C_c, and C_d.

(*a*) *Lower Llandovery*. The basal Llandovery sandstones and conglomerates rest on Bala mudstones with a sharp boundary; these are followed by mudstones with occasional sandy beds, all totalling 1880 ft. (600 m.) in the centre of the area, but thinning to 1200 ft. (400 m.) in the south-west (Andrew 1925, pp. 392, 402).

Fossil communities. No fossils are recorded in A_a. In the southern part of the area, the *Stricklandia* Community is present in A_b, and both *Stricklandia* and *Clorinda* occur in A_c, but the shelly faunas become sparse or absent in the north (Andrew 1925, pp. 396–7), that is, towards the basin.

Correlation. Andrew (1925, p. 403) considered 'on faunal and lithological grounds': that his units 'A_a, A_b, and A_c appear accurately to represent A_1, A_2, and A_3 of the southern part of the Llandovery area'. It is of importance to note that the top 20 ft. of the 'Bala' beds of Garth contain '*Glyptograptus* cf. *persculptus* and *Mesograptus* cf. *modestus* var. *parvulus*, which . . . are usually associated with the basal zone of the Valentian' (Andrew 1925, p. 392). This fauna indicates the *persculptus* Zone, the base of which is now conventionally taken (e.g. Toghill 1968) as the base of the Llandovery in the graptolite sequence. If Andrew was correct in equating his unit A_a with the A_1 sandstone at Llandovery itself, then the base of the formation is probably diachronous. The latter conclusion is supported by recent unpublished sedimentological work by Dr. M. A. Woollands.

(*b*) *Middle Llandovery*. Only a small thickness of mudstones is present in a restricted area in the south-east of the Garth area (Andrew 1925, p. 397). The few specimens recorded are suggestive of the *Clorinda* Community. Andrew suggested a correlation with B_3 of Llandovery on the basis of lithological resemblance (Andrew 1925, p. 403), but its age is still not definitively known.

(*c*) *Upper Llandovery*. The lower three Upper Llandovery units of Andrew (C_a, C_b, C_c) comprise a sequence of mudstones, argillaceous sandstones, and rather prominent conglomerates which is very variable in thickness (0–300 ft., 0–100 m.). The upper unit (C_d) consists of 150–1000 ft. (50–330 m.) of olive-green and purple mudstones, similar in colour and lithology to the high Llandovery of many other areas; it overlaps earlier

beds, coming to rest on A_b at the extreme south-western and north-eastern ends of the area, according to the mapping of Andrew. C_d passes up without a break into beds containing the basal Wenlock zone of *Cyrtograptus murchisoni* (Andrew 1925, p. 400).

Fossil communities. Andrew's faunal lists (1925, pp. 398–9) show that C_a contains a *Pentamerus* Community, which indicates a shallowing after the Middle Llandovery. C_b has yielded a fauna which includes *Pentamerus*, *Stricklandia*, and *Clorinda*, suggesting a return to deeper water. It is not possible to determine the community present in C_c, but increase in depth is again shown by the graptolites present in C_d.

Correlation. The Upper Llandovery of Garth can be tentatively correlated with the beds of Llandovery on gross lithological and faunal grounds. Andrew and Jones (1925, p. 412) suggest it may be equivalent to C_{4-6}. The presence of beds with *Monograptus priodon* and *Monoclimacis crenulata* conformably below the basal Wenlock shows that the highest Llandovery is present in this area.

CHRONOLOGICAL SUMMARY

Text-fig. 11 illustrates the chronological sequence of Llandovery deposits in the Welsh Borderland. It brings out the fact that, although the spread of the sea was continuous from Lower Llandovery times, there were several gaps in sedimentation. In general, however, there is evidence of a progressive deepening at any one locality.

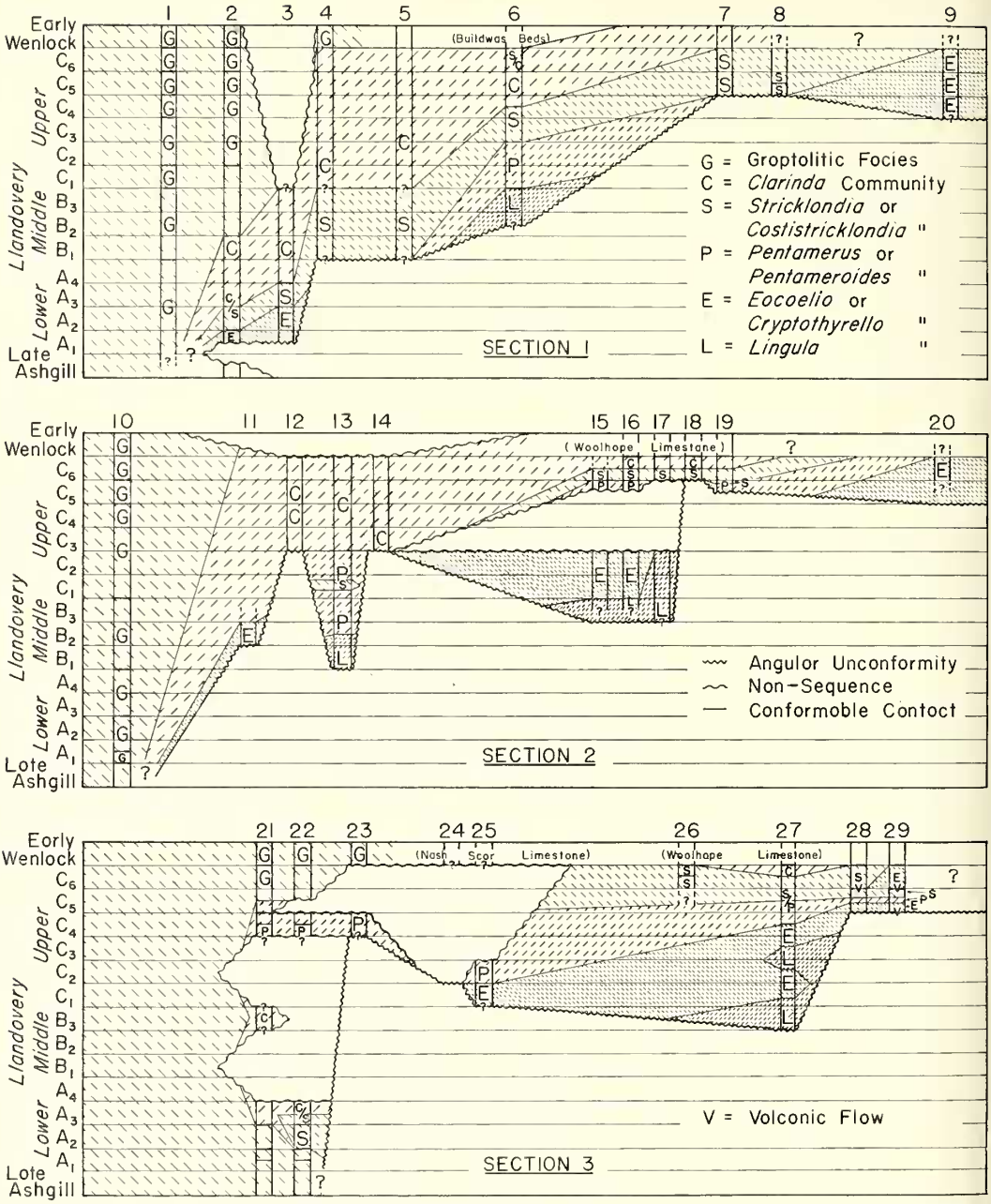
Lower Llandovery (A_{1-4}) times

The shelf was narrow during the Lower Llandovery, and deposits are confined to an area west of Welshpool and Garth (text-fig. 12). In the basin area of Central Wales (text-fig. 11, cols. 1, 10, 21, and 22), basal Llandovery graptolitic shales follow above similar Ashgill sediments without a break. At Trannon and Llanidloes this facies continues throughout the Lower Llandovery, but at Garth *Stricklandia* and *Clorinda* Communities are present, showing that shallowing took place there in A_{2-3} times. This was probably followed by a depositional break, as no A_4 has been proved at Garth.

On the edge of the basin at Meifod and Welshpool (text-fig. 11, cols. 2 and 3), there was uplift of Ashgill sediments prior to the deposition of beds containing A_{1-2} shallow-water *Cryptothyrella* Communities. In Shropshire, to the east (text-fig. 11, cols. 5, 6, 11–14), the Caradoc and earlier rocks are seen to be considerably folded before the Middle Llandovery. If these movements are correlated with the basal A_1 non-sequence at Meifod and Welshpool, then it may be that the acme of this folding occurred at the very beginning of the Silurian. After the initial uplift, the shallow-water A_{1-2} beds at Meifod and Welshpool are followed by deeper-water A_3 *Stricklandia* and *Clorinda* Communities. The general subsidence characteristic of the Welsh Borderland throughout the Lower Silurian thus started as early as A_{2-3} times.

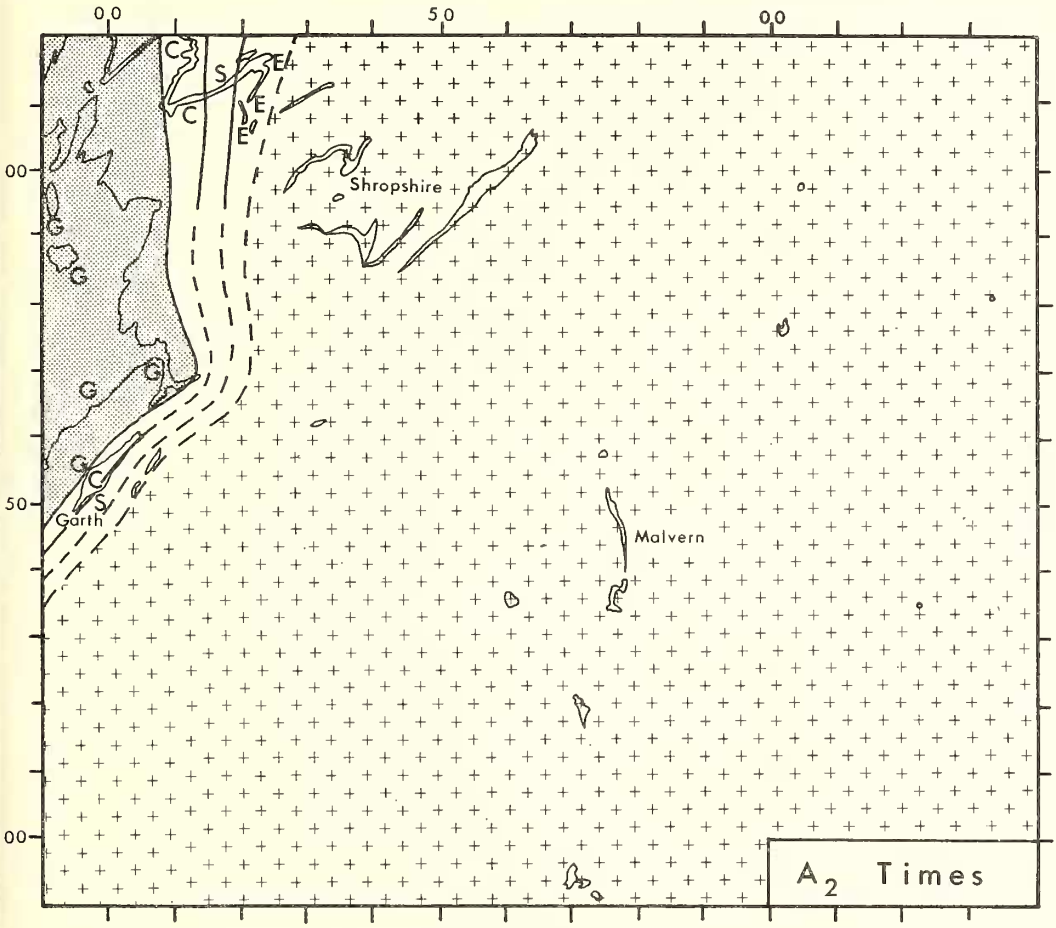
Middle Llandovery (B_{1-3}) times

In the basin (text-fig. 11, cols. 1 and 10), the graptolitic facies continues without break; this facies spread over the basin margin at Meifod (text-fig. 11, col. 2) in B_2 time, when the *Clorinda* Community was replaced by graptolites. At about the same time, the sea



TEXT-FIG. 11. Three sections across the Welsh Borderland (see text-fig. 1 and 3) showing communities plotted against time.

deepened at Welshpool (text-fig. 11, col. 3) and spread over West Shropshire (text-fig. 11, cols. 4, 5, 11, and 13) and may have just reached the Malverns (text-fig. 11, cols. 15–17) by the end of Middle Llandovery times. It is worth noting here that there are no Middle Llandovery sediments in nearby sections at Eaton Farm and Wistanstow



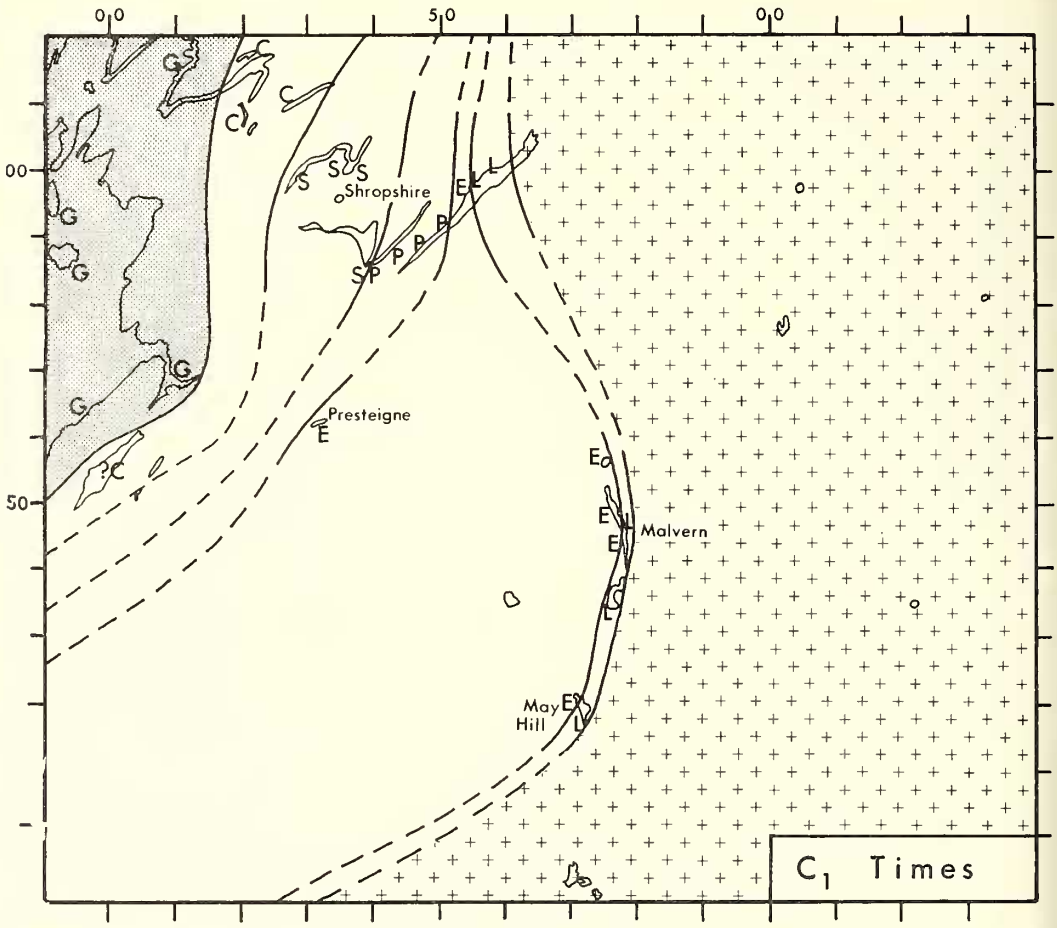
TEXT-FIG. 12. Palaeogeography of the area during Lower Llandovery (A_2) time. E, *Cryptothyrella* Community; S, *Stricklandia* Community; C, *Clorinda* Community; G, graptolitic facies.

Note. The coastline is shown as a smooth curve, but we envisage a coastal topography perhaps similar to Essex at the present time (this applies also to text-fig. 13 and 14). The size of some of the smaller outcrops is enlarged for greater clarity, and the Upper Severn Estuary is omitted.

(text-fig. 11, cols. 12 and 14). The earliest deposits at these localities contain C_{2-3} *Clorinda* Communities; this shows that the sea was deep before sedimentation commenced, and that the advance of the sea was not everywhere accompanied by a supply of sediments. Thus the sea probably extended over the Eaton Farm and Wistanstow areas in Middle Llandovery time.

Early Upper Llandovery (C_{1-3}) times

At Trannon, Meifod, and Llanidloes (text-fig. 11, cols. 1, 2, and 10) the graptolite facies continues, both in the basin and on the edge of the shelf (text-fig. 13). In West Shropshire (text-fig. 11, cols. 4 and 5) the sea is seen to have deepened with the replace-

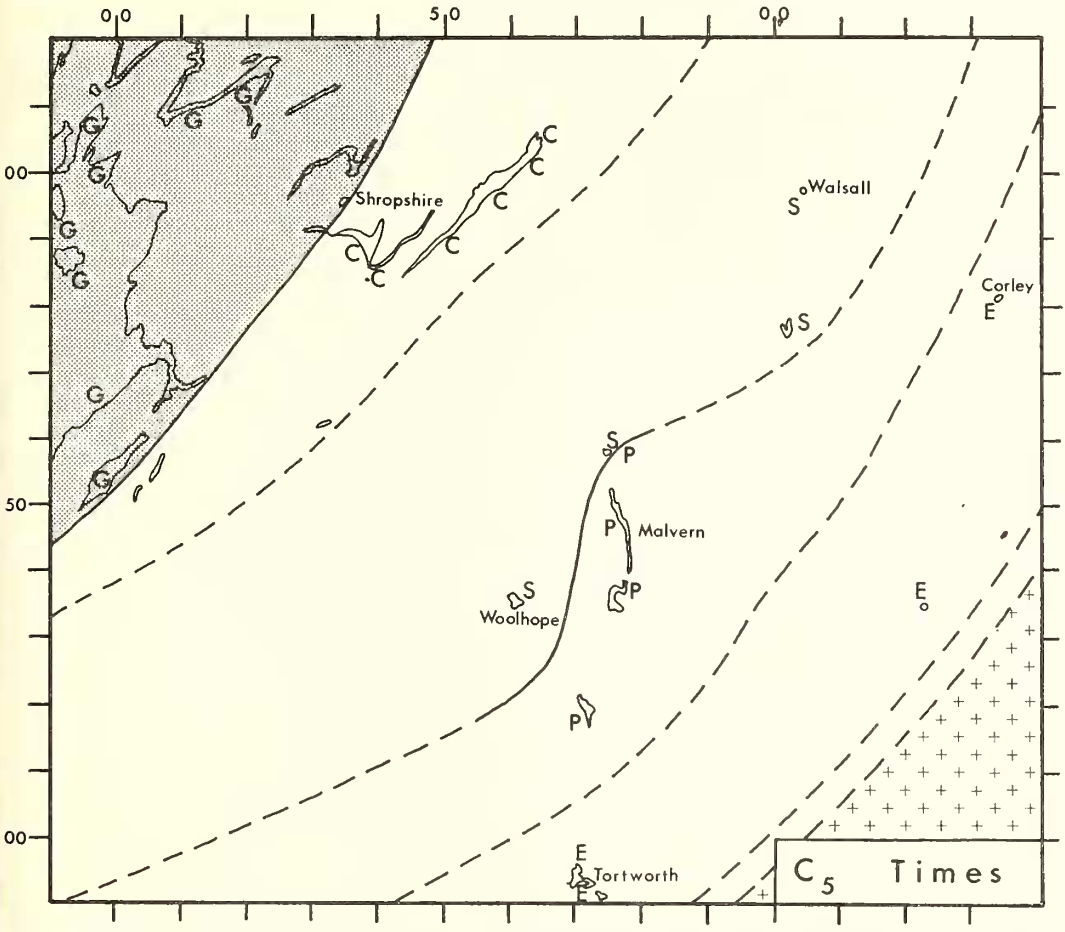


TEXT-FIG. 13. Palaeogeography of the area during early Upper Llandovery (C_1) timc. L, *Lingula* Community; E, *Eocoelia* Community; P, *Pentamerus* Community; S, *Stricklandia* Community; C, *Clorinda* Community; G, graptolitic facies.

ment of the *Stricklandia* Community by the *Clorinda* Community. South of the Long-mynd (text-fig. 11, col. 13) the communities show a minor reversal, but there was an over-all deepening from C_1 to C_3 times. At neighbouring sites (text-fig. 11, cols. 12 and 14) sedimentation commenced for the first time with the deposition of deep-water *Clorinda* Communities resting directly on Pre-Cambrian and Ordovician rocks.

In the Wenlock Edge outcrop, and in the Malverns and at Presteigne (text-fig. 11, cols. 6, 15–17, and 25), there are undoubted early Upper Llandovery sediments; these contain shallow-water communities showing the progressive deepening so characteristic

of this transgression. There is a sequence from a basal *Lingula* Community (not exposed at Presteigne) deepening to *Eocoelia* or *Pentamerus* Communities. At May Hill (text-fig. 11, col. 27) there is a minor reversal in the progressive deepening as *Lingula* and *Eocoelia* Communities alternate.



TEXT-FIG. 14. Palaeogeography of the area during late Upper Llandovery (C_5) time. E, *Eocoelia* Community; P, *Pentameroides* Community; S, *Costistricklandia* Community; C, *Clorinda* Community; G, graptolitic facies.

At Garth and Builth (text-fig. 11, cols. 21–3) no beds of C_{1-3} age are present, this is probably to be accounted for by non-deposition in a sea of *Pentamerus* Community depth, as this community is present above the non-sequence in beds of C_4 age.

Late Upper Llandovery (C_{4-6}) times

During this time, basin facies (the Pale Shales) continue at Garth (text-fig. 11, col. 21), but, in Wenlock times, graptolitic deposits are present at Builth as well (col. 23); an eastwards spread of this deep environment thus presumably occurred in C_6 times (text-fig. 14). A similar C_6 spread probably took place over the edge of the basin from

Montgomeryshire into West Shropshire (text-fig. 11, cols. 2–4); this deepening of the sea may also be related to the turbidites at Minsterley (which are of late Upper Llandovery [post C_4] or early Wenlock [pre-*riccartonensis* Zone] age).

On Wenlock Edge (text-fig. 11, col. 6), the progressive deepening, mentioned above, continues through most of C_{4-6}, but in late C_6 time there is an indication of slight shallowing in the beds immediately below the Buildwas Beds.

From sandstone pebbles in the Upper Carboniferous north-east of Coventry (text-fig. 11, col. 9), *Eocoelia* has been found, ranging in age from C_4 to C_6. However, at Walsall and Rubery (text-fig. 11, cols. 7 and 8) the earliest Silurian deposits contain C_5 beds with *Costistricklandia* Communities and rest directly on Cambrian rocks; here, as in Shropshire during C_{1-3} (see above), we have strong indications that the sea was present at Walsall and Rubery well before sedimentation commenced. The evidence from Lower Lemington (text-fig. 11, col. 20) suggests a shallow sea there in C_6 times, but the local base of the Silurian is unseen.

In the Malvern areas (text-fig. 11, cols. 15–19), no beds of C_{3-4} age are known; this non-sequence is followed by C_5 beds with *Pentameroides* and *Costistricklandia* Communities which overlap the C_{1-2} deposits (which contain *Lingula* and *Eocoelia* Communities), and rest in places on the Pre-Cambrian. Text-fig. 11 shows that there is a progressive deepening of the sea across this non-sequence; thus there is no suggestion of any marine regression during C_{3-4} time in the Malvern area.

A different type of stratigraphical break is present beneath the Nash Scar Limestone at Presteigne and Old Radnor (text-fig. 11, cols. 24 and 25); a shallow-water Wenlock algal limestone rests unconformably on C_2 beds (with a *Pentamerus* Community) at Presteigne, and on Pre-Cambrian at Old Radnor. There must have been shallowing during this interval, and local uplift may well have occurred here during the late Upper Llandovery.

The progressive deepening, seen or inferred for C_{4-6} beds of most areas, was also present to the south of the Malverns in the May Hill and Tortworth areas (text-fig. 11, cols. 27–9). At May Hill the communities range from *Eocoelia* through *Pentameroides* and *Costistricklandia* to *Clorinda*, and at Tortworth the Stone succession (col. 28) also shows a progressive sequence. This last sequence contains a 15-ft. (5-m.) thick basalt within the beds containing the C_6 *Costistricklandia* Community. But at the other end of the Tortworth Inlier (at Charfield Green, text-fig. 11, col. 29) the basalt has thickened to 150 ft. (50 m.), and is followed directly by beds containing an *Eocoelia* Community. We conclude that the sudden shallowing of the shelf sea by 150 ft. is directly responsible for the replacement of a *Costistricklandia* Community by an *Eocoelia* Community; this implies that the depth range of the intervening *Pentameroides* Community is significantly less than 150 ft.

CONCLUSIONS

The elucidation of the evolution of several brachiopod genera has enabled wide correlation of the 13 subdivisions of the Llandovery established in the type area by O. T. Jones. Recognition of similar assemblages of fossils at different times has led to the establishment of five main animal communities. In the Silurian the marine communities of the shelf were largely epifaunal and relatively independant of substrate; depth was thus the main controlling factor in community distribution.

In the shelf regions on the Welsh Borderland, the Llandovery always rests unconformably on older rocks; on the margin of the basin there is only a small break at the very base of the Lower Llandovery; and in the basin of Central Wales there is conformity between the Ordovician and Silurian. From A_1 to C_6 there was a progressive spread of the sea to the east and south. In the Lower Llandovery marine deposits are present at Welshpool and Garth; by Middle Llandovery times West Shropshire had been submerged; and by early Upper Llandovery (C_1) times the sea had transgressed as far as the Malverns and May Hill; it did not reach Tortworth until the late Upper Llandovery (C_5). The theory (Jones 1938) that there was a sudden submergence of the whole area at the beginning of the Upper Llandovery cannot now be accepted.

With few exceptions, each local sequence shows a progressive increase of depth with time. This progressive depth increase can even span periods of non-deposition, for example the C_5 beds above the non-sequence in the Malverns were laid down in deeper water than in C_2 beds below the break. We have concluded that, where a deeper-water community is present at the base of a local sequence, the sea was present for some time before deposition commenced. It follows that the spread of the sea with time was even more uniform than the sedimentary sequences record. It also follows that there were periods when no sediments were being deposited in certain parts of the sea floor; this may have been due either to lack of sediment supply or to no deposition or erosion in current-swept areas.

The Welsh Borderland is on the south-eastern margin of a Lower Palaeozoic geosyncline which included the Lake District, the Southern Uplands of Scotland and much of central Ireland. Both this margin and the western margin in County Galway show an extension of the sea during Llandovery times, but at the same time north-east Newfoundland (and perhaps also parts of the Midland Valley of Scotland, for example, Lesmahagow), show a transition from deep-water basin sediments to shelf or even non-marine conditions. When the Welsh Borderland is viewed as part of this larger region, it seems improbable that the advance of the sea during Llandovery times was due to eustatic deepening.

Although there was probably little structural control of sedimentation from place to place within the Welsh Borderland at this time, there were three major tectonic regions affecting the area:

(i) The basin region to the west which subsided rapidly, accommodating large thicknesses of sediment (nearly 10 000 ft. (3300 m.) of Llandovery beds at Llanidloes).

(ii) The shelf region, which subsided slowly throughout the whole of Llandovery time, and upon which thinner sediments accumulated.

(iii) A region of uplands to the south and east, which provided the sediment for both of the other regions.

REFERENCES

ANDREW, G. 1925. The Llandovery rocks of Garth, Breconshire. *Q. Jl geol. Soc. Lond.* **81**, 389–406, pl. 22.

—— and JONES, O. T. 1925. The relations between the Llandovery rocks of Llandovery and those of Garth. Ibid. 407–16.

BASSETT, D. A. 1963. The Welsh Palaeozoic geosyncline: a review of recent work on stratigraphy and sedimentation. *In The British Caledonides*, ed. M. R. W. Johnson and F. H. Stewart, 35–69. Oliver & Boyd, Edinburgh and London.

BUTLER, A. J. 1937. On Silurian and Cambrian rocks encountered in a Deep Boring at Walsall, South Staffordshire. *Geol. Mag.* **74**, 241–57.

CAVE, R. 1965. The Nod Glas sediments of Caradoc age in North Wales. *Geol. Jnl*, **4**, 279–98, pl. 12.

COCKS, L. R. M. 1967*a*. Llandovery stropheodontids from the Welsh Borderland. *Palaeontology*, **10**, 245–65, pl. 37–9.

—— 1967*b*. Depth patterns in Silurian Marine Communities. *Marine Geol.* **5**, 379–82.

—— and RICKARDS, R. B. (in press). Five boreholes from Shropshire and the relationships of shelly and graptolitic facies in the Lower Silurian. *Q. Jl geol. Soc. Lond.*

—— and WALTON, G. 1968. A large temporary exposure in the Lower Silurian of Shropshire. *Geol. Mag.* **105**, 390–7.

CURTIS, M. L. K. 1955. Lower Palaeozoic. *In Bristol and its adjoining counties*, ed. C. M. MacInnes and W. F. Whittard, 3–7. Brit. Assn Adv. Sci. Bristol.

EASTWOOD, T., WHITEHEAD, T. H., and ROBERTSON, T. 1925. The geology of the country around Birmingham. Sheet 168. *Mem. Geol. Surv.* (*U.K.*). 1–152, pl. 1–7.

ELLES, G. L. and WOOD, E. M. R. 1901–18. A monograph of British graptolites. *Palaeontogr. Soc.* [*Monogr.*], 1–539, pl. 1–52.

GARDINER, C. I. 1920. The Silurian rocks of May Hill. *Proc. Cotteswold Nat. Fld Club*, **20**, 185–218, pl. 1.

GARWOOD, E. J. and GOODYEAR, E. 1918. On the geology of the Old Radnor District, with special reference to an algal development in the Woolhope Limestone. *Q. Jl geol. Soc. Lond.* **74**, 1–30, pl. 1–7.

GREEN, G. W. 1962. *In Summ. Progr. geol. Surv.* (*U.K.*) (for 1961), p. 29.

GREIG, D. C., WRIGHT, J. E., and MITCHELL, G. H. 1968. Geology of the country around Church Stretton, Craven Arms, Wenlock Edge and Brown Clee. Sheet 166. *Mem. geol. Surv.* (*U.K.*). 1–379, pl. 1–13.

GROOM, T. T. 1899. The geological structure of the Southern Malverns, and of the adjacent district to the west. *Q. Jl geol. Soc. Lond.* **55**, 129–69, pl. 13–15.

—— 1900. On the geological structure of portions of the Malvern and Abberley Hills. Ibid. **56**, 138–97, pl. 8.

—— 1910. The geology of the Malvern and Abberley Hills, and the Ledbury District. *Geol. Assoc., Jubilee Vol.* 698–738, pl. 23.

HOLL, H. B. 1865. On the geological structure of the Malvern Hills and adjacent districts. *Q. Jl geol. Soc. Lond.* **21**, 72–102.

JONES, O. T. 1925. Geology of the Llandovery District. Part 1: the southern area. Ibid. **81**, 344–88, pl. 21.

—— 1938. On the evolution of a geosyncline. Ibid. **94**, lx–cx.

—— 1947. The geology of the Silurian rocks west and south of the Carneddau Range, Radnorshire. Ibid. **103**, 1–36, pl. 1.

—— 1949. Geology of the Llandovery District. Part 2: the northern area. Ibid. **105**, 43–64, pl. 3.

JONES, W. D. V. 1945. The Valentian succession around Llanidloes, Montgomeryshire. Ibid. **100** (for 1944) 309–32, pl. 14.

JUKES, J. B. 1853. On the occurrence of Caradoc sandstone at Great Barr, South Staffordshire. Ibid. **9**, 179–81.

KING, W. B. R. 1928. The geology of the district around Meifod, Montgomeryshire. Ibid. **84**, 671–702, pl. 52.

KIRK, N. H. 1951. The Upper Llandovery and Lower Wenlock rocks of the area between Dolyhir and Presteigne, Radnorshire. *Proc. geol. Soc. Lond.* **1471**, 56–8.

LAMONT, A. and GILBERT, D. F. L. 1945. Upper Llandovery Brachiopoda from Coneygore Coppice and Old Storridge Common, near Alfrick, Worcs. *Ann. Mag. nat. Hist.* [11] **12**, 641–82, pl. 3–7.

LAPWORTH, C. 1878. The Moffat series. *Q. Jl geol. Soc. Lond.* **34**, 240–346, pl. 11–13.

LAWSON, J. D. 1955. The geology of the May Hill Inlier. Ibid. **111**, 85–116, pl. 6.

PHILLIPS, J. 1848. The Malvern Hills, compared with the Palaeozoic Districts of Abberley, Woolhope, May Hill, Tortworth, and Usk. *Mem. geol. Serv.* (*U.K.*) **2** (1), 1–330, pl. 1–3.

PHIPPS, C. B. and REEVE, F. A. E. 1967. Stratigraphy and geological history of the Malvern, Abberley and Ledbury Hills. *Geol. Jnl*, **5**, 339–68.

POCOCK, R. W. 1930. The *Petalocrinus* Limestone horizon at Woolhope (Herefordshire). *Q. Jl geol. Soc. Lond.* **86**, 50–63, pl. 6, 7.

—— WHITEHEAD, T. H., WEDD, C. B., and ROBERTSON, T. 1938. Shrewsbury District, including the Hanwood Coalfield. Sheet 152. *Mem. geol. Surv.* (*U.K.*). 1–297, pl. 1–8.

READING, H. G. and POOLE, A. B. 1961. A Llandovery shoreline from the Southern Malverns. *Geol. Mag.* **93**, 295–300, pl. 15, 16.
—— —— 1962. Malvern structures. Ibid. **99**, 377–9.
REED, F. R. C. and REYNOLDS, S. H. 1908. On the fossiliferous Silurian rocks of the southern half of the Tortworth Inlier. *Q. Jl geol. Soc. Lond.* **64**, 512–45.
REYNOLDS, S. H. 1907. A Silurian inlier in the Eastern Mendips. Ibid. **63**, 217–40, pl. 18.
—— 1912. Further work on the Silurian rocks of the Eastern Mendips. *Proc. Bristol Nat. Soc.* **3**, 76–82.
—— 1924. The igneous rocks of the Tortworth Inlier. *Q. Jl geol. Soc. Lond.* **80**, 106–12, pl. 7, 8.
—— 1929. The geology of the Bristol District. *Proc. Geol. Assoc.* **40**, 77–103.
ROBERTSON, T. 1926. The section of the new railway tunnel through the Malvern Hills at Colwall. *Summ. Progr. geol. Surv.* (*U.K.*) (for 1925), 162–75.
ST. JOSEPH, J. K. S. 1935. A critical examination of *Stricklandia* (= *Stricklandinia*) *lirata* (J. de C. Sowerby) 1839 *forma typica*. *Geol. Mag.* **72**, 401–24, pl. 16, 17.
—— 1938. The Pentameracea of the Oslo region. *Norsk geol. Tidsskr.* **17**, 225–336, pl. 1–8.
SHOTTON, F. W. 1927. The conglomerates of the Enville Series of the Warwickshire Coalfield. *Q. Jl geol. Soc. Lond.* **83**, 604–21, pl. 47, 48.
SOLLAS, W. J. 1879. On the Silurian district of Rhymney and Pen-y-lan, Cardiff. Ibid. **35**, 475–507, pl. 24.
SQUIRRELL, H. C. and TUCKER, E. V. 1960. The geology of the Woolhope Inlier (Herefordshire). Ibid. **116**, 139–85, pl. 15.
STRAHAN, A. 1913. Batsford (or Lower Lemington) Boring, near Moreton-in-Marsh. *Summ. Progr. geol. Surv.* (*U.K.*) (for 1912), 90–1.
SYMONDS, W. S. 1872. *Records of the rocks*. John Murray, London, 433 pp.
TOGHILL, P. 1968. The graptolite associations and zones of the Birkhill Shales (Llandovery) at Dobb's Linn. *Palaeontology*, **11**, 654–68.
TYLER, W. H. 1925. Notes on Sheet 48 N.W. (Shropshire). *Proc. Geol. Assoc.* **36**, 377.
WADE, A. 1911. The Llandovery and associated rocks of north-eastern Montgomeryshire. *Q. Jl geol. Soc. Lond.* **67**, 415–59, pl. 33–6.
WATTS, W. W. 1885. On the Igneous and Associated Rocks of the Breidden Hills in East Montgomeryshire and West Shropshire. Ibid. **41**, 532–46.
WHITTARD, W. F. 1928. The stratigraphy of the Valentian rocks of Shropshire: the Main Outcrop. Ibid. **83** (for 1927), 737–59, pl. 56, 57.
—— 1932. The stratigraphy of the Valentian rocks of Shropshire. The Longmynd-Shelve and Breidden Outcrops. Ibid. **88**, 859–902, pl. 58–62.
WHITTINGTON, H. B. 1938. The geology of the district around Llansantffraid ym Mechain, Montgomeryshire. Ibid. **94**, 423–57, pl. 38, 39.
WILLIAMS, A. 1951. Llandovery brachiopods from Wales with special reference to the Llandovery District. Ibid. **107**, 85–136, pl. 3–8.
WILLS, L. J. and LAURIE, W. H. 1938. Deep sewer trench along the Bristol road from Ashill Road near the Longbridge Hotel to the City Boundary at Rubery, 1937. *Proc. Birmingham nat. Hist. phil. Soc.* **16**, 175–80, pl. 1.
—— WILKENS, L. G. and HUBBARD, G. H. 1925. The Upper Llandovery Series of Rubery. Ibid. **15**, 67–83.
WOOD, E. M. R. 1906. The Tarannon Series of Tarannon. *Q. Jl geol. Soc. Lond.* **62**, 644–701, pl. 47, 48.
ZIEGLER, A. M. 1964. The Malvern Line. *Geol. Mag.* **101**, 467–9.
—— 1965. Silurian marine communities and their environmental significance. *Nature, Lond.* **207**, 270–2.
—— 1966*a*. Unusual stricklandiid brachiopods from the Upper Llandovery beds near Presteigne, Radnorshire. *Palaeontology*, **9**, 346–50, pl. 58.
—— 1966*b*. The Silurian brachiopod, *Eocoelia hemisphaerica* (J. de C. Sowerby) and related species. Ibid. 523–43, pl. 83, 84.
—— COCKS, L. R. M. and BAMBACH, R. K. 1968. The composition and structure of Lower Silurian marine communities. *Lethaia*, Oslo, **1**, 1–27.
—— and BOUCOT, A. J. 1968. North American Silurian animal communities. *In* W. B. N. Berry, and A. J. Boucot. Silurian of North America. *Mem. geol. Soc. Am.* (in press).

APPENDIX 1

Localities of collections in Oxford University Museum

Area	*Locality*	*Field designation*	*Grid reference*
Tortworth	1	T–M–A	(ST/7268 9212)
	2	T–R–A	(ST/7233 9234)
	3	T–D–A	(ST/6962 9390)
May Hill	4	M–N–A	(SO/7014 2104)*
	5	M–D–A	(SO/7055 1987)
	6	M–L–A	(SO/7052 1838)
	7	M–L–B	(SO/7049 1838)
	8	M–L–C	(SO/7048 1839)
	9	M–Q–A	(SO/7066 1994)
	10	M–Q–B	(SO/7067 1993)
	11	M–H–A	(SO/7047 1811)
	12	M–B–A	(SO/7041 1974)
	13	M–B–B	(SO/7039 1973)
	14	M–G–C	(SO/7051 2097)
	15	M–F–D	(SO/6874 2154)
	16	M–F–A	(SO/6874 2154)
	17	M–S–A	(SO/6918 2261)
	18	M–S–B	(SO/6932 2270)
	19	M–S–C	(SO/6936 2271)
	20	M–F–C	(SO/6872 2155)
	21	M–O–A	(SO/6869 2244)
	22	M–G–B	(SO/7055 2103)
Malvern Hills	23	H–O–A	(SO/7533 3764)
	24	H–H–A	(SO/7487 3595)
	25	H–T–A	(SO/7494 3492)
	26	H–G–A	(SO/7612 3811)
	27	H–G–D	(SO/7612 3811)
	28	H–G–E	(SO/7612 3811)
	29	H–G–F	(SO/7608 3811)
	30	H–P–A	(SO/7646 4594)
	31	H–C–A	(SO/7672 4442)
	32	H–R–A	(SO/7613 4784)
	33	H–S–A	(SO/7616 4723)
Old Storridge Common	34	H–L–A	(SO/7467 5115)
	35	H–F–C	(SO/7444 5124)
	36	H–M–A	(SO/7430 5152)
	37	H–M–B	(SO/7430 5152)
	38	H–L–C	(SO/7464 5108)
	39	H–L–B	(SO/7464 5111)
	40	H–F–B	(SO/7438 5114)
	41	H–M–C	(SO/7405 5167)
Ankerdine Hill	42	A–A–A	(SO/7352 5625)
	43	A–H–A	(SO/7376 5696)
	44	A–Q–A	(SO/7363 5630)
	45	A–K–A	(SO/7347 5690)

* Collections from loose blocks.

Area	*Locality*	*Field designation*	*Grid reference*
Wenlock Edge	46	Morrellswood	(SJ/6284 0637)
	47	Boathouse A	(SJ/6210 0379)
	48	Boathouse B	(SJ/6206 0390)
	49	Boathouse C	(SJ/6205 0398)
	51	Sheinton B	(SJ/6116 0310)
	52	Merrishaw A1	(SJ/5805 0090)
	53	Merrishaw A2	(SJ/5805 0090)
	54	Merrishaw B	(SJ/5852 0065)
	55	Domas	(SJ/5936 0062)
	56	Hughley	(SO/5605 9747)
	58	Wall-u-Heywood	(SO/5120 9276)
	59	Ticklerton	(SO/4821 9088)
	60	Onny River	(SO/4260 8532)
Church Stretton	61	Marshbrook	(SO/4341 8982)
	62	Hillend Farm	(SO/3956 8769)
Norbury	63	Norbury	(SO/3587 9284)
Bog	65	Bog A	(SO/3510 9815)*
	66	Bog B	(SO/3510 9815)*
Minsterley	67	Ox Wood Dingle	(SJ/2909 0123)
	68	Venusbank	(SJ/3534 0125)
	69	Hope Outlier	(SJ/3482 0140)
	70	Hope Quarry	(SJ/3551 0208)
	71	Hope Brook	(SJ/3578 0212)
	72	Josey's Wood A	(SJ/3656 0213)
	73	Josey's Wood B	(SJ/3653 0221)

APPENDIX 2

Localities of collections in British Museum (Natural History)

Area	*Locality*	*Field designation*	*Grid reference*
Wenlock Edge	50	Sheinton A	(SJ/6099 0324)
	57	Gilberries	(SO/5115 9361)
Norbury	64	Linley Wall	(SO/3587 9284)*
Minsterley	74	Josey's Wood C	(SJ/3641 0216)
	75	Minsterley Lane	(SJ/3803 0487)

APPENDIX 3

Localities of collections in United States National Museum

Area	*Locality*	*U.S.N.M. no.*	*Grid reference*
Tortworth	76	10215	(ST/6879 9574)
	77	10217	(ST/7056 9428)
	78	10218	(ST/7267 9206)
	79	10219	(ST/7267 9206)
	80	10220	(ST/7055 9426)
	81	10221	(ST/7055 9426)
	82	10223	(ST/7045 9440)*

* Collections from loose blocks.

Area	*Locality*	*U.S.N.M. no.*	*Grid reference*
May Hill	83	10225	(SO/6927 2263)
	84	10226	(SO/6927 2263)
Woolhope	85	10230	(SO/5804 3730)
	86	10232	(SO/5948 3564)
Old Storridge Common	87	10237	(SO/7496 5156)
Presteigne	88	10242	(SO/3177 6343)
	89	10243	(SO/3197 6334)
	90	10244	(SO/3160 6320)
	91	10245	(SO/3153 6316)
	92	10246	(SO/3155 6317)
	93	10247	(SO/3018 6235)
Eastern Mendips	94	12936	(ST/6755 4585)*

* Collections from loose blocks.

A. M. ZIEGLER
Department of the Geophysical Sciences
University of Chicago
Illinois 60637, U.S.A.

L. R. M. COCKS
Department of Palaeontology
British Museum (Natural History)
London S.W. 7

W. S. McKERROW
Department of Geology and Mineralogy
Parks Road
Oxford

Typescript received 1 March 1968